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Contents

GEAR LUBRICATION SYMPOSIUM

Part II—The Testing of Gear Lubricants

The Development of a Test Method for Gear Lubricants on the IAE Machine
By Mechanical Tests of Lubricants Panel

From Test Machine to Gear-Box
By J. R. Hughes

Road and Laboratory Wear Tests of Gear Oils
By H. L. Bingham and J. G. Withers

Production of Lubricant Test Gears
By R. D. B. Stone

The Testing and Performance of Lubricants for High-speed Gears
By J. Greenwood and R. W. Morton

Developments in the Specification and Testing of Lubricants for Hypoid Axles
By A. Towle

The Testing and Selection of Gear Lubricants
By H. J. Watson

Service Tests in Rear Axles of Buses and Trolley-buses
By H. E. Styles and A. T. Wilford

Abstracts Additions to Library New Members

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GEAR LUBRICATION SYMPOSIUM

PART II. THE TESTING OF GEAR LUBRICANTS

The Chairman: Part I dealt with the more basic, or perhaps academic, phases of our subject. Now we shall deal with the more practical aspects of the evaluation of gear lubricants and methods of testing. I will ask Mr Fogg to summarize the papers in this session.

A. Fogg, presenting his summary, said: This section of the symposium is concerned with a series of papers on the testing of gear lubricants, and there is no need to emphasize how desirable it is for both producers and users to have at their disposal some simple means of testing gear lubricants. The difficult nature of the problem is well illustrated by the different outlooks and, to some extent, the conflicting views expressed by the authors of papers in this group.

Of the eight papers under review, one—by Stone of the British Gear Grinding Company—is concerned, not with tests and test results, but with the preparation of specimens for a particular test machine. I have had personal contact with this work, and know how extremely valuable it has been to many other workers in this field, particularly those who participated in the experiments of the IP Working Group on Gear Oil Testing.

Where actual gears are used as specimens for lubricant testing, it is obvious that they must be produced not only to a satisfactory design but to very close physical and metallurgical limits. Stone's gears are for use on the IAE 3¼-inch-centres machine, and he divides his problems into three groups: (1) material; (2) heat treatment; (3) dimensional accuracy. On material, he refers to En.34 and En.39 as the most commonly used and probably most representative steels, particularly for tests on oils for automotive and aircraft applications. These are case-hardening steels, but the author hints that through-hardening test gears might be worth consideration. As a further aspect of material, he discusses the form of gear blank, and although it is common practice to use upset forgings, he quotes from a MIRA investigation which indicated that gears cut from bar stock would be equally satisfactory.

After brief reference to preliminary machining operations, he deals with the very important question of heat treatment, which possibly has a greater influence on gear performance with a given lubricant than any other factor. To obtain uniformity and a fine grain structure, which he considers desirable, his gears are subjected to a double-quench treatment, whilst other precautions in the carburizing operation are mentioned; his surface-hardness target is a minimum of 750 V.P.N.

For final dimensional accuracy the formed-wheel-grinding system is used, and attention is drawn to the vital need to avoid excessive heat

generation during the grinding process. The relation between grinding abuse, surface finish, and grinding-wheel-grit characteristics is discussed, and the author states that he obtains greater consistency with coarser wheels. Although rougher finishes result, there is no evidence that these are detrimental from the lubrication standpoint; on the contrary, the author suggests there may be some benefit, although he appreciates that much remains to be learned about the influence of surface finish on lubrication problems. Finally, brief reference is made to methods of checking the final dimensional accuracy.

Turning to the other papers, the problem of actual testing is approached in a variety of ways, involving tests in normal vehicle service, experiments on test vehicles on the road, tests on service components in the laboratory, tests on special gear machines and on special test rigs designed to simulate gear operation. Styles and Wilford introduce their paper by referring either to the non-existence of suitable performance tests or to a lack of confidence in their ability to predict behaviour in practical use, and conclude that, for some properties at least, service tests are necessary.

Their usual procedure involves the running of similar units lubricated with a " standard " oil and the oil under test, under closely similar conditions. A point is made that the difficulties in conducting tests involving large numbers of vehicles are much greater than might be supposed. A selection of vehicles for test presents no real problem, but the main difficulties arise from the fact that, in an organization similar to that to which the authors are attached, operating conditions differ from garage to garage, on each of the routes served by a particular garage, and even for individual vehicles running on a particular route. In addition to the difficulties arising from variations in operating conditions, the authors stress the need to recognize the fact that no two individual test units can be regarded as precisely identical. Consequently, a large number of units is required, and statistical techniques are necessary both in planning the tests and in reviewing the data subsequently obtained. Groups of several hundred units may have to be compared before a reliable answer is obtained.

The authors have used the procedure of obtaining a mass of data from large numbers of operating units in the successful selection of lubricants for engines and pre-selective gear-boxes, but have been less successful with rear-axle lubricants. The authors mention that, during a period of several years, this testing technique has been applied to compounded oils, lead-soap lubricants, filtered cylinder oils of both low and high viscosity index, and EP lubricants. Apart from castor oil, all the others severely oxidized after some 12,000 miles in service, the deterioration being evidenced by an excessive increase in viscosity. Variability in the wear of the gear mechanism, however, defeated all attempts to differentiate one lubricant from another. However, it was possible to draw the general conclusion that oils of lower viscosity than had hitherto been employed might be worth while investigating.

In service the main objection to the type which concerns the authors is high power loss and, consequently, increased fuel consumption. Severe increase in viscosity, therefore, is to be avoided at all costs. Previous experiments by the authors indicated that the use of oxidation inhibitors would, for all practical purposes, eliminate any increase in lubricant

viscosity, and accordingly large-scale tests have been carried out with low-viscosity oils containing various types of oxidation inhibitors. Although the tests carried out in this way have shown a fair amount of variability, they have clearly indicated that even after 45,000 miles of operation, oxidation-inhibited oil is in a much better condition than an uninhibited oil after only 15,000 miles of use. It was also apparent that the inhibited oil tended to show an accelerated rate of viscosity increase from about 34,000 to 45,000 miles, and, in consequence, the authors' company has standardized on an oil-change period of 34,000 miles. Such operational changes could only be justified on the basis of tests of the nature described.

In contrast with the large-scale service testing advocated by Styles and Wilford, Towle submits a case for carrying out tests on what are virtually standard components, namely motor-car rear axles, in the laboratory, associated with a limited amount of testing on selected vehicles under specified conditions.

First, he refers to developments in the use of hypoid axles, and forecasts that the time is not far distant when all spiral-bevel axles will disappear from production. It is, therefore, he says, becoming more and more urgent that some specification should be standardized for lubricants for hypoid axles. He then discusses some of the requirements of hypoid lubricants, such as, load-carrying capacity and ability to minimize wear of gears and bearings; they should also be stable, compatible, non-corrosive, and should have low foaming and channelling tendencies. He refers next to American experience and gives a brief historical review, completing this section of his paper with full details of American rigs and procedures, which consist essentially of (1) a high-torque, low-speed test carried out on a production axle in the laboratory, and (2) a high-speed, low-torque test carried out on a production motor car on the road or on a chassis dynamometer.

As a natural development, he then sets out in some detail the arguments for establishing an equivalent British test procedure and describes experiments which he has carried out to this end. He has followed the pattern of the American precedent, and divides his test procedures into a high-torque, low-speed test and a high-speed, low-torque test. In the former case he uses a Standard Vanguard axle and gives a detailed description of the associated equipment. Full details are also given of the test conditions. Judgment of the oil is based on examination of the components at the end of a given period of testing. The high-speed, low-torque test is still under development, but is being carried out on a Vanguard car at the MIRA Proving Ground, using a test procedure which can easily be fitted in to the road system. In addition to these two mechanical tests, a moisture-corrosion test is carried out, again on a Vanguard rear axle.

The author gives details of possible types of failure of hypoid gears, which he sets out as follows: burnishing, scratching, rippling, ridging, pitting, spalling, scoring, scuffing, and wear. Some excellent photographs of failures are given, but his classification may seem to be unnecessarily elaborate, whilst his association of the term " surface fatigue " with several of these phenomena is open to challenge.

Finally, Towle refers to possible correlation with small-scale laboratory machines, but is firmly of the opinion that no correlation is possible and

that tests for hypoid oils must be carried out on hypoid axles. His Table IV, comparing the results of his high-torque test with those obtained on similar oils in the IAE gear machine, is of special interest in view of the opinions expressed in a subsequent paper on a similar issue. Towle gives the results for six oils tested by both procedures, and although there is lack of agreement in only one out of six, he decides that there is no correlation.

Bingham and Withers, in contrast to Towle, point out the need, in the development of additives and finished oils, for a less-expensive procedure than the full-scale axle tests of the U.S. Army specification. Concentrating on the wear aspect, they emphasize the need for extensive service testing as a background for comparison with any laboratory procedure. Their paper covers both the compilation of wear data from axles in vehicles on the road and interim experiments with the Four-ball machine as the basis of a laboratory test procedure.

Their road work has covered experiments on twelve post-war cars, with test distances, in general, of 5000 miles. The road conditions were varied to include mixed traffic and open-country driving. Wear was determined by measurement of the iron content of the oil in the axle at various times during a test. Such a method is known to be difficult to carry out with the necessary degree of accuracy, and the authors discuss some of the problems they have had to face. Their ways of dealing with their difficulties may stimulate discussion, although the details essential for an objective judgment of the technique appear to be insufficient, presumably because of the need for brevity. After an initial period steady, continuous rates of wear are reported which clearly differentiate between the various lubricants examined. This conception of a steady rate of wear of gears, which, presumably, are not scuffing, is a controversial one, and, in the discussion, alternative explanations may be suggested for this apparent steady increase in the iron content of the oil. Their laboratory work has been carried out on the Four-ball machine used, in the authors' terms, as a " wear tester," with freedom from incipient seizure effects.

In relating their results on the road to those in the laboratory, the authors draw attention to some of the difficulties involved, but to overcome them in future they intend to introduce a reference oil suitable for both spiral and hypoid bevels. Nevertheless, a fair degree of correlation is claimed, two oils only being excepted. The relevant figures appear to be contained in Table III. This interpretation is in marked contrast to Towle's, referred to earlier.

The next four papers are concerned mainly with the use of special gear rigs or gear-simulation machines. Hughes reviews present laboratory test methods for determining load-carrying capacity and frictional properties of gear lubricants and points out some of their limitations. Axle rigs he regards as being suitable only for " go " or " not go " tests because of the too wide dimensional limits on production gears. Special gear rigs, such as the IAE machine, require specially made, highly accurate gears. They are, therefore, expensive to run, and provide only comparative data. The IAE machine, he claims, has the further limitation that its capacity is inadequate for hypoid lubricants, the gears sometimes failing by surface fatigue—a material failure—rather than by scuffing.

He then refers to disk machines with both constant and variable angular

velocities, which generally are cheap to run and allow measurements to be made both of load-carrying capacity and frictional properties. The machines do not, however, measure a fundamental property of an oil, and translation of results to service, he states, requires years of experience of testing in the laboratory and in the field. He claims, very rightly, that laboratory measurement of a fundamental property independent of the method used to determine it is desirable, but is it not probable that the fundamental property is one not of a lubricant alone but of a lubricant and a pair of surfaces? Hughes appears to accept this, or to take a similar view, by introducing a discussion on Blok's postulate of a critical temperature for failure of each combination of lubricant and sliding system.

He refers to results obtained on this basis accounting for behaviour of oils in the IAE machine, and also quotes figures for failure temperatures on the Two- and Four-ball machines for a wide range of oil viscosities. The translation of results of this nature to practice would still be a problem. It would require much more experimental data and a better understanding of the mechanism of gear lubrication—a goal well worth pursuing.

Watson gives details of, and experiences with, a disk machine for testing oils for spur, helical, bevel, and worm gears. His machine uses disks positively driven at constant angular velocity but with provision for varying the so-called "slide–roll" ratio. Details are given of test procedures for determining friction and load-carrying capacity. After briefly reviewing typical results obtained, the author concludes that, although the disk machine is far from perfect and there are unresolved discrepancies between results from the machine and from service, it has been a great help over periods of years in the selection of lubricants for many applications.

The paper by Morton and Greenwood and the report of the Mechanical Tests of Lubricants Panel both deal exclusively with gear-oil testing on the IAE machine. Because of the prominence of this machine in the papers in this part of the Symposium, it should perhaps be mentioned that a brief history and description of the machine is given in a paper by Mansion in Part I. For a full description, reference must be made to previously published literature.

The report states that the Panel's terms of reference were: "To consider and report upon the desirability and possibilities of standardization of a test, or tests, for gear-box and back-axle lubricants." Because of the difficulty of interpreting results of tests on gear-simulation machines, the Panel decided that the best procedure would be a test employing gears. IAE machines were available in several laboratories and, consequently, this machine was selected for a series of correlation programmes. Four laboratories took part in the first programme, which was concerned with three reference oils, two being straight mineral oils of widely differing viscosity, and the third a higher-viscosity oil with a blend of EP additive.

The results were not entirely satisfactory, and a review was made of possible causes of inconsistency, such as choice of steel, heat treatment, hardness, tip relief of gears, and cleaning procedure. Closer control and more precise specification of these factors was made in subsequent work.

A further difficulty, however, was that the capacity of the machine appeared to be inadequate for powerful EP oils and, in a second correlation programme, attempts were made to increase the range of the machine by

increasing sliding speed between the gear-teeth, first by using gears with a smaller number of teeth, and secondly by increasing the rotational speed of the gears. In the first case the change was very small; in the second case an examination of seven oils by three laboratories, at double the usual speed, showed that even under this condition a satisfactory test for hypoid-type oils could not be developed. The recognition of scuffing was difficult, and in some cases pitting, *i.e.*, surface fatigue of the gears, occurred before scuffing. The Panel concludes that the machine is a satisfactory instrument for rating the load-carrying capacities of straight and mildly doped oils, but, as yet, is unsuitable for oils of the hypoid type.

Morton and Greenwood are mainly concerned with using the IAE machine as a test device in the development of lubricants for high-speed gears. They also regard a machine which uses gears, rather than one which uses simple forms of test specimens, as a better proposition for this purpose, although they emphasize the necessity for good reproducibility and the difficulty of attaining this requirement with gear specimens.

Reference is made to earlier work sponsored by the former Ministry of Aircraft Production, which indicated the value of the IAE machine for rating oils for aero-engine gears, and which presumably influenced the authors in their choice of equipment. Their test procedure is basically unaltered from that originally accepted by the former MAP, except that oil supply is based on quantity instead of supply pressure. It has been found unnecessary to increase the test speed, and good correlation with practice is claimed. Results for different kinds of practice are given.

Considerable attention has been given to the generally acknowledged difficulty of obtaining satisfactory test specimens, and very extensive tests have been carried out on this aspect of the problem, including various steels, heat treatments, and gears from three different manufacturers. The question of regrinding specimens for further use has also received attention. It is concluded that the variability of results is encouragingly small, and that by controlling test-gear quality, employing skilled operators, and using a high standard of maintenance, variability can be reduced still further. Further work has involved examination of such factors as lubricant supply rate, supply temperature, and viscosity, in addition to speed.

The authors conclude that the IAE machine is a very valuable laboratory rig for the testing of either mineral or synthetic-type lubricants for applications such as those in which the most critical features are high-speed, heavily loaded gears, and they suggest that there are good grounds for adopting this as a standard test method.

To sum up, my conclusions are that, although much encouraging progress is reported in these papers, it is apparent that gear-oil testing is still a debatable problem, and that much more experimental work is necessary before it can be satisfactorily and finally resolved. Further work should preferably be on a co-operative basis—an excellent precedent having been set by the Institute—or with very close liaison between the workers involved.

The papers presented at the evening session follow.

THE DEVELOPMENT OF A TEST METHOD FOR GEAR LUBRICANTS ON THE IAE MACHINE

By The Mechanical Tests of Lubricants Panel of Standardization Sub-committee No. 5

Introduction

Many test machines to evaluate the load-carrying capacities of gear oils have been developed, particularly since the introduction of the hypoid gear. Although most of these machines produce a sliding motion between loaded test pieces, and so to some extent simulate the motion of a pair of gear-teeth, the exact interpretation of their results in terms of gear lubrication is sometimes difficult, and the load-carrying capacity of a given lubricant is then obtainable only by recourse to tests on the gears themselves. For this reason, the Mechanical Tests of Lubricants Panel, whose terms of reference were " to consider and report upon the desirability and possibilities of standardization of a test, or tests, for gear-box and back-axle lubricants," decided that the most desirable test would be one employing gears.

At this time (1945) there were several IAE 3¼-inch centres gear rigs already working, and although the gears employed were spur gears and, therefore not directly related to back-axle reduction gears, it was felt that the results would probably be capable of direct interpretation and would certainly be more convincing than tests in simulation apparatus.

A Working Group was therefore appointed to study the suitability of this machine for testing with a view to the standardization of a test method.

The IAE 3¼-inch centres gear rig [1] was developed in the late 1930s by the Research Department of the former Institution of Automobile Engineers from a slightly smaller machine borrowed from the Delft Laboratories of the Royal Dutch Shell Group. Several of these machines had been used for test purposes for some time prior to the formation of the Working Group, so that it was possible to start the co-operative experimental work without delay, using test conditions already found to be satisfactory by users.

This paper contains an account of the activities of the Working Group as recorded in the minutes of the various meetings and in the reports of test work issued by the participating laboratories with, in addition, the results of a statistical analysis.

First Correlation Programme

The first task of the Working Group was to examine the repeatability and reproducibility of the test using the existing test conditions (see Table I).

In order to cover a wide range on the expected scuffing-load scale, two straight mineral oils from the same crude, of SAE 20 and 50 viscosity grade respectively, were selected for these tests. In addition, in order to investigate any limitations which there might be in evaluating oils for the lubrication of hypoid gears, a blend of an EP additive in the SAE 50 oil was included. The results of these tests are given in Table I.

TABLE I

Scuffing Tests on the First Series of Oils for Correlation Purposes

Conditions :

Pinion speed	2000 r.p.m.	Loading increment	5 lb (on 18-inch lever)
Oil temperature	90° C.	Running period	5 min.
Oil flow	½ pt/min.	Rest period between loads	5 min.
Gear material	As shown.		

Oil	Scuffing load, lb							
	Lab. 1		Lab. 2		Lab. 3		Lab. 4 †	
		Mean		Mean		Mean		Mean
SAE 20	35		15/45				10	
	35		15/35				10	
			15/45				10	
							15	
							15	
		35		28·3			15	13
SAE 50	65		50		65		40	
	105		45		65		35	
	55		50		65		45	
	40		45		70		40	
	55		50				45	
	65	64		48		66		41
SAE 50 EP	190		>180				170	
	185		>180				175	
			190 *				>175	
							>175	
		187·5		>180			>165	>165
Gear material used :	En.39		En.34		En.34		En.39	

* Pitted.
† "Approach" scuffing only.

These results indicated that the test, as developed at that time, was not completely satisfactory, and that there were probably many factors which required consideration. Experience gained by some of the co-operating laboratories in prior work has suggested that the scatter of results obtained with En.39 steel (4½ per cent Ni–Cr–Mo) was very large, and that En.34 (2 per cent Ni–Mo) was to be preferred. For this reason En.34 had been specified as the gear material for the co-operative tests, but owing to supply difficulties some laboratories had been unable to obtain such gears. After further work of a private nature many of the laboratories had come to the conclusion that there was little, if any, difference between the scuffing loads obtained on a given oil with these two steels. Because of machining and heat-treatment difficulties which were prone to occur with En.39, the Working Group favoured En.34, which was adopted as standard for the IP work. The heat treatment of the test gears was also reviewed, and it was decided to follow a procedure as close as possible to industrial practice. The hardness of the gears for these tests was specified as 740 ± 40 V.P.N.

In discussing the co-operative programme, it became clear that the criterion of scuffing varied from one laboratory to another, and this was probably one of the causes of the differences in results sometimes obtained. In many cases results were considered unsatisfactory owing to scuffing in "approach" occurring at a lower load than scuffing in "recess." One user had overcome this difficulty by taking the mean of these two values, and had found good agreement with the value obtained when complete scuffing, *i.e.*, both "approach" and "recess," occurred at one increment of load. Another laboratory did not continue the test beyond the load at which "approach" scuffing occurred, and yet another, which had installed a thermocouple to indicate the temperature of the oil flung off the gears, regarded the load at which the oil temperature first increased rapidly as the scuffing load, irrespective of whether scuffing had occurred in "approach" or "recess."

It was realized that the phenomenon of scuffing was associated with the tip relief applied to the gears. For the experiments summarized in Table I a relief of 0·0003 to 0·0005 inch had been applied to both wheel and pinion, and it was suggested that the test would be more satisfactory if more relief were given in "approach" so as to delay the scuffing in this position so that complete scuffing occurred at a single load. To this end, a relief in "approach" of 0·0004 to 0·0006 inch, and in "recess" of 0·0002 to 0·0004 inch was adopted, and subsequent work showed that such a modification greatly assisted in the equalization of the "approach" and "recess" scuffing loads.

It was agreed by all users that some scatter of results was inevitable, and that the results of the test should be examined statistically. Variations in tooth profile were believed to affect the repeatability of results, and the need for very accurately made gears was stressed. The test gears already supplied were, however, of high quality, so that little improvement could be expected in this direction. Metallurgical and physical changes produced by "running-in" could also conceivably affect the scuffing performance of the gears, but no evidence for any effect due to this cause had been observed with the gears used for these tests, and so any question of "running-in" the gears before the start of the test was dropped. Contaminants in the system were also regarded as possibly contributing towards the scatter of results and, to diminish this possibility, a cleaning procedure to be adopted in these tests was drawn up.*

Hypoid Oils and Second Correlation Programme

The probable inability of the IAE 3¼-inch centres gear rig in its original form to cover the whole range of gear lubricants from a light straight mineral oil to an EP oil was realized at the start of the Working Group's study, and the results obtained with the first series of correlation oils

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* *Proposed Cleaning Procedure :*

Gears : Thoroughly cleaned in petroleum ether before test.

Rig : (*a*) After using doped oil : 1. Flush with SBP 2 for 30 min; 2. Flush out with oil to be tested for 30 min. Drain for 30 min; 3. Fill with test oil.

(*b*) After using an undoped oil : 1. Flush out with oil to be tested for 30 min. Drain for 30 min; 2. Fill with test oil.

tended to confirm this. A suggestion had been made that gears with a smaller number of teeth would help in this respect by providing increased sliding velocities between the teeth. Accordingly, such gears had been used by one laboratory, but the reduction in scuffing loads obtained was disappointingly small. Details of the gears used and test results are given in Table II which includes results obtained with the 15/16-toothed gears for comparison.

TABLE II

Scuffing Tests on the First Series of Correlation Oils Using 12/13 * *Toothed Gears*

Conditions :

Pinion speed	20000 r.p.m.
Oil temperature	90° C.
Oil flow	¼ pt/min.
Gear material	En.34 steel.

Oil	Scuffing load, lb † Lab. 4		
	12/13 Gears		15/16 Gears ‡
		Mean	
SAE 20	15		
	10		
	15	13	13
SAE 50	30		
	30		
	25		
	25		
	25	27	41
SAE 50 EP		>150	>165

† "Approach" scuffing load. ‡ From Table I.

Another way of increasing the sliding speed between the teeth was simply to increase the rotational speed of the rig and use the standard test gears, and therefore, for the tests on the second series of oils, which included EP types, a pinion speed of 4000 r.p.m. was specified. Tests with these oils were completed by three laboratories with the results shown in Table III.

It was found that even at the increased speed, pitting of the teeth occurred before scuffing in many cases when using oils of the hypoid type, so that a satisfactory scuffing test for these oils could not be developed at this speed. The recognition of failure by scuffing, when pitting did not occur, had been found by all workers to be difficult, and likewise hindered the development of a satisfactory test. For example, some oils would carry on long after the first signs of failure, and the gears would be "re-polished" only to fail at some higher load. Some wear would possibly accompany the

* The gears used were 4 D.P. of twelve and thirteen teeth, running at an extended centre distance so that the nominal pressure angle of 20° was increased to 25° 22′ 16″. Compared to the normal 15/16-toothed gears, the tip sliding speed in approach was increased by 11·6 per cent.

TABLE III

Scuffing Tests on the Second Series of Oils for Correlation Purposes

Conditions :

Pinion speed	4000 r.p.m.
Oil temperature	90° C.
Oil flow	½ pt/min.*
Gear material	En.34 steel.

Oil	Scuffing load, lb					
	Lab. 4		Lab. 5		Lab. 6	
		Mean		Mean		Mean
Pool 17	55		45		55	
	62·5		50		50	
	60					
	52·5	58		47·5		52·5
Pool 17 + 6% rape oil	65		75		75	
	72·5		60		80	
	75					
	70	71		67·5		77·5
Castor oil	70		115		95	
	70		80		95	
	67·5		95			
	67·5	69		96·7		95
Pool 17 + 6% Anglamol 40	87·5		110		95	
	105		100		90	
	105					
	102·5	100		105		92·5
Pool 17 + 5% sulphurized fatty oil	97·5		70		85	
	100		75		85	
	95					
	92·5	96		72·5		85
Pool 17 + 10% Anglamol 77	160 †		150		135	
	170 †		135		125	
	155 †				135	
	150 ‡				125	
		159		142·5	115	127
Pool 17 + 10% Anglamol 82	135 †		170		130	
	142·5 †		145		120	
	140 †				130	
	135 †				140	
					130	
					100	
		138		157·5	110	123

* Except Lab. 4, who used 1 pt/min.

† Scuffing accompanied by severe tooth damage in the form of pitting and plastic flow of tooth surfaces.

‡ Complete surface breakdown by pitting.

initial failure, but as the practical significance of such a phenomenon is unknown, much more investigational work is necessary to clarify the position.

Significance of Results Obtained on the IAE 3¼-inch Centres Gear Rig

Mention has already been made of the intention to treat experimental results statistically. When this decision was made there were insufficient data available from the co-operative tests alone, and an estimate of the repeatability of the method was based on some results on the 3¼-inch centres gear rig obtained by MIRA. In his report the statistician stated, "The repeatability standard deviation of the method is 13 per cent, and is independent of the gear profiles, the oil temperature, viscosity, and the gear material on the evidence of the present results."

The results presented in Table III have also been examined for estimates of repeatability and reproducibility. For ease of analysis, nine of the sixty-five results were omitted, leaving two results for each oil for laboratories 5 and 6, and four results for each oil for laboratory 4. Examination of the homogeneity of the error variance from laboratory to laboratory showed that there was a significant difference between that of laboratory 5 and those of laboratories 4 and 6, but that the value obtained for laboratory 5 was in excellent agreement with the value obtained in the analysis of the MIRA results quoted above. It was suggested that for some reason or other the results obtained by laboratories 4 and 6 did not reflect the true error variance of the test. To be on the safe side it is wisest to base the estimate of repeatability * on the largest value of the error variance, and when this is done a value of 48 per cent is obtained. This means that the larger of two results should not exceed the smaller, in 95 per cent of cases, by more than 48 per cent. The corresponding estimate of reproducibility * at the same significance level is 58 per cent. Thus, fair agreement between the repeatability and the reproducibility of the test is indicated, as should be expected.

Conclusions

As a machine to evaluate the load-carrying capacity of gear lubricants, the IAE 3¼-inch centres gear rig has the advantage that gears are used as the test pieces so that there is a direct connexion between the test and practice, at any rate as far as spur gears are concerned. Helical gears, with their greatly reduced dynamic loads as a result of better engagement conditions and back-axle gears, may respond to the lubricant in a somewhat different way from spur gears, but in the absence of any field data this point cannot be decided.

A fairly large number of tests is possibly required for highly significant results, but if a lower level of probability is acceptable, say 95 per cent, then the mean of four results will probably be within ±15 per cent of the true value. This involves the use of two pairs of test gears, and as the gears may be re-ground and used again at least once, the cost of the test does not become too high.

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* Defined as $[(\text{anti-log } 3\sigma) - 1] \times 100$, where σ is the appropriate standard deviation.

The repeatability of the test is to some extent dependent on the ability to recognize scuffing. With undoped mineral oils, and even with oils containing EP additives, the occurrence of scuffing is accompanied by unmistakable visual surface damage, and there is no doubt about the load at which it occurs.

With other oils, and particularly those of the hypoid type, the onset of scuffing is not so marked, and difficulties are experienced in deciding exactly when scuffing has taken place. A similar phenomenon occurs with castor oil, for example, which may explain the difference in results between laboratories in Table III. With hypoid oils a further difficulty arises in that pitting of the teeth occurs at high loads before scuffing has taken place, so that the rating of this type of oil on the machine is not possible.

It thus appears that the machine is a satisfactory instrument for rating the load-carrying abilities of straight and mildly doped oils, but as yet is unsuitable for oils of the hypoid type.

Acknowledgment

Thanks are due to all those who in any way contributed to the progress of this work, and in particular to :—

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for assistance in the development of the design and specification of the test gear; and G. W. Sears and G. P. Davies, who carried out the statistical analysis.

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FROM TEST MACHINE TO GEAR-BOX: PROBLEMS ASSOCIATED WITH THE TRANSLATION OF LABORATORY TEST RESULTS INTO PREDICTIONS OF FIELD-SERVICE PERFORMANCE OF GEAR LUBRICANTS

By J. R. Hughes *

Summary

A brief outline is given of present test methods for evaluating in the laboratory the load-carrying capacity and frictional properties of a gear lubricant. Some limitations of these methods are pointed out, and it is suggested that a more fundamental approach to the evaluation of gear-lubricant performance should be made. The postulate of Blok that each lubricant and sliding system has a critical temperature for failure is put forward for consideration as a possible means of translating the results of laboratory tests into predictions of field-service performance.

Introduction

Two of the properties of a gear lubricant which are measured in the laboratory are :—

(*a*) its load-carrying capacity, or ability to prevent metal-to-metal contact and consequent seizure;
(*b*) its frictional properties.

Before the development of lubricating oils containing EP additives, the suitability of an oil for a given gear application could usually be assessed from a knowledge of its viscosity, since the load-carrying capacity was related to the viscosity. The development of EP lubricants, the load-carrying capacities of which were largely independent of viscosity, necessitated in turn the development of suitable laboratory apparatus for assessing the performance of such oils.

The frictional properties of a gear lubricant are important, particularly for worm gears for which a low coefficient of friction is desirable to maintain a high efficiency and a low operating temperature. Consequently, laboratory apparatus for measuring the influence of oils on the coefficient of friction had to be developed.

Development of Laboratory Test Machines

The best way of evaluating a gear oil is to test it in the gears it is to lubricate in service. Although this is possible in some applications, it is impracticable to have in the laboratory all types of gear unit, and therefore it is necessary to select representative ones if such a method is to be used. Even then, inaccuracies acceptable in gears for service are usually too great for any test which must give reasonably repeatable results.

* Thornton Research Centre, " Shell " Refining & Marketing Co. Ltd.

Therefore, laboratory tests which use gears must either be go/no-go tests as, for example, the hypoid-axle rigs used in the CRC L-20 test, or must use specially made, highly accurate gears as, for example, the IAE 3¼-inch centres gear rig.[1, 2, 3] Both types of gear rig have disadvantages. The go/no-go test cannot generally distinguish between oils of similar performance, and is therefore unsuitable for research purposes. The rig using special gears is expensive to run, and its results are not easy to interpret in terms of service performance except in a comparative way. In addition, the cost and difficulty of making highly accurate gears increase greatly from spur to more complex gears such as worm gears, so that in general only spur gears are used for such rigs. The load-carrying capacity of oils intended to lubricate spur and helical gears can be assessed on spur-gear rigs, but frequently hypoid lubricants cannot, since on the IAE 3¼-inch centres gear rig, for example, the gears fail by pitting before scuffing can occur when such lubricants are tested.

In view of the limitations of gear rigs, many machines have been devised which use test pieces of a simple geometric form to simulate the kinematics of gear-tooth contacts. The test pieces are either readily available, like bearing balls or races, or can be manufactured easily, like disks. The slide/roll conditions and the line loading of spur gears, for example, can be simulated by rotating together in contact two disks, with different peripheral velocities. By choosing the diameters and rotational speeds of the disks suitably, the conditions at any point of contact of a given set of gears may be simulated. If the disk surfaces move in opposite directions at the point of contact, the most severe conditions in the engagement of worm gears are said to be simulated.[4] A well-known example of this type of machine is the David Brown disk machine.[4, 5] In this machine the disks are driven at uniform speeds, so that the slide/roll conditions match those obtaining at only one point in gear engagement. If a more exact simulation of gear-tooth action is desired, the disks may be driven at non-uniform speeds so chosen that one complete cycle of tooth engagement is completed every revolution of the disks. This method is used in the Brown–Boveri [6] and MIRA [7] disk machines. Disk machines may be used for measuring the load-carrying capacity and frictional properties of oils over a wide range of conditions, and in addition for studying the influence of lubricants on the pitting and wear of gears.

Gear and simulation rigs both represent attempts to reproduce service conditions in the laboratory. Such machines do not measure a fundamental property of the oil, but something which depends in addition on the geometry and nature of the mating surfaces. Translation of results from test machines into service performance can be done either by comparing the results with similar ones on an oil of known service performance or by using the accumulated experience of years of testing of lubricants both in the laboratory and in the field. It would be preferable if some fundamental property of the lubricant, which was independent of the method used to determine it, could be measured in the laboratory.

Viscosity is one such property, and it is possible by the methods first described by Martin,[8] and later elaborated by others, to calculate the load-carrying capacity of straight mineral oils due to their viscosity, assuming hydrodynamic lubrication. It has been found that higher loads can be

carried than those calculated, which points to the possibility that even straight mineral oils have some other property besides viscosity, which affects their lubricating ability. The Four-ball Machine [9] was developed to measure this property of straight mineral oils and also the protection against seizure provided by EP additives. In this machine hydrodynamic lubrication of the classical type is almost entirely eliminated by the nature of the contact which is between one rotating ball and three fixed balls. Any protection against seizure measured in this machine is due to the inherent EP properties of the lubricant. The interpretation of results, except in a comparative way, is difficult without a more complete knowledge of the mechanism of lubricant failure in gears than is at present available.

Laboratory Test Machines in Specifications

Many specifications for gear lubricants include a performance test, which is frequently merely the measurement of load-carrying capacity or friction on a given test machine at one set of operating conditions.

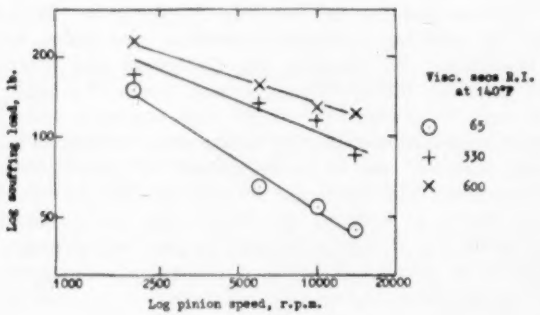

Fig 1

EFFECT OF SPEED ON SCUFFING LOAD OF HIGH-SPEED GEARS

The load-carrying capacity and frictional properties of a lubricant vary according to the conditions under which it is used. The following figures illustrate this point. Although they were obtained on test-machines, it is probable that similar results could be obtained on service units.

Fig 1 shows the influence of speed on the load-carrying capacity of three mineral oils. The oils were tested in the Thornton high-speed gear rig,[10] load-carrying capacity having been assessed by measuring the load on the gears to cause scuffing of the teeth in a 5-minute run. It is apparent that the comparative performance of the three oils is different according to the speed, although their rating is unchanged.

Fig 2 shows the influence of speed on the load-carrying capacity of a number of oils, both straight mineral and additive type. The tests were carried out on a simulation rig, the Two-ball Machine,[11] the load-carrying capacity having been assessed by measuring the load to cause scuffing of the balls in a 1-minute run. The rating of this set of lubricants varies according to the sliding speed.

Fig 3 shows the influence of speed and temperature on coefficient of friction. The results were obtained from a David Brown type disk machine using one disk of steel and one of bronze. The additive-type oil is only shown to advantage at the higher temperature.

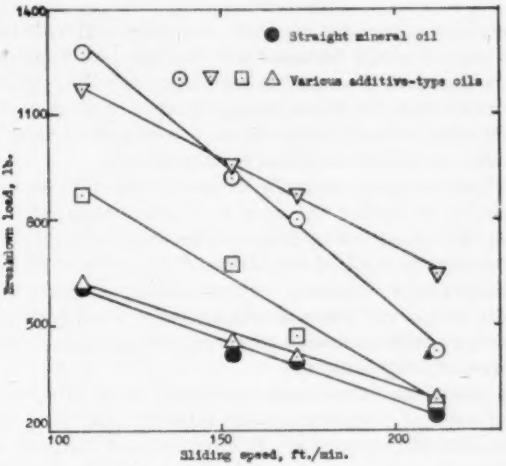

FIG 2

EFFECT OF SPEED ON BREAKDOWN LOAD MEASURED ON TWO-BALL MACHINE

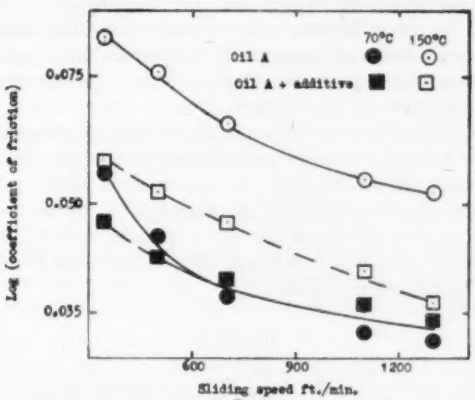

FIG 3

INFLUENCE OF SPEED AND TEMPERATURE ON COEFFICIENT OF FRICTION

Thus, since oils are rated differently according to the test conditions and will perform differently in service according to the conditions of operation, it is apparent that a performance clause in a specification must be either a test to simulate the most severe conditions likely to occur in the application considered or a test covering a range of conditions. If a test such as the Four-ball Machine is used, it is essential that adequate correlation of service

and laboratory results is available before any test conditions or test criteria are selected.

Future Developments

Present methods of evaluating gear lubricants in the laboratory are satisfactory if only a rough indication of service performance is required. For the better utilization of available lubricants and the continued development of improved ones for more stringent applications, a deeper insight into the mechanism of gear lubrication is required so that the desirable properties of oils are known and can be measured.

Taking the load-carrying capacity of gear lubricants as an example, it is still not possible to predict the load at which a straight mineral oil will permit scuffing of a given set of gears. The classical equations for hydrodynamic lubrication as applied by Martin [8] to gears predict failure loads far below those actually obtained. Even if the equations are modified to allow for effects which will increase the allowable load carried, such as the increase of viscosity with increased pressure, the calculated failure loads are still below those actually obtained.

Blok [12] has postulated that each combination of lubricant and sliding system has a " critical temperature for failure " and that once this temperature is reached in the contact, lubrication will fail and seizure occur. The temperature in the contact, according to Blok, is higher than the bulk temperature of the gears by a temperature flash, of very short duration, due to the generation of frictional heat in the contact. Lane [11] has further elaborated the postulate by suggesting that the surface layers of the path of contact will be at a higher temperature than the bulk temperature because of the repeated applications of frictional heat, and that the temperature flash must be superimposed on to this " surface temperature " to obtain the temperature in the contact.

Although it is difficult to conceive any physical meaning for the " critical temperature for failure," it has been shown to account for the behaviour of straight mineral oils in the IAE 3¼-inch centres gear rig,[13] and work on the Two-ball machine has lent further support.[11] Some recent tests have enabled values to be calculated for the supposed critical temperature for failure of a number of straight mineral oils, on both the Two-ball and Four-ball machines, as shown in Table I.

Table I

Lubricant viscosity, Redwood I at 140° F, sec	Critical temperature for failure, °C	
	Two-ball Machine	Four-ball Machine
45	244	220
65	250	194
140	266	213
170	280	256
330	272	250
420	285	273
600	293	256

There is thus a reasonable measure of agreement between the results obtained from the two machines.* The materials used in both sliding systems are similar, but, whereas the conditions in the Four-ball Machine are pure sliding, in the Two-ball Machine there is also a rolling component. However, it is possible to predict fairly accurately the results obtainable on one machine from results obtained on the other.

The lubricating ability of an oil can thus be expressed by its critical temperature for failure, which at present can be calculated from results on laboratory test rigs and which perhaps will eventually be capable of being measured directly. Whether the postulate of Blok is the only one which can explain the behaviour of oils in gears remains to be seen, but at least it does seem possible that eventually a knowledge of the supposed critical temperature for failure of an oil may enable its performance in a given gear set to be predicted.

However, before the postulate can be applied to practice, even empirically, a considerable amount of experimental data is necessary. Even if the values of the critical temperature calculated from results on laboratory test rigs are acceptable and can be taken as applying to gears, it is necessary to know the temperature in the contact of the gears before the performance of a given lubricant can be predicted or a suitable lubricant recommended. To calculate these temperatures it is required to know the coefficient of friction in the contact and the dependence of the equilibrium surface temperature in the path of contact on the geometry, material, and operating conditions of the gears.

In addition, the physical meaning of the hypothetical critical temperature for failure must be ascertained before the postulate can be applied practically with any degree of confidence and before direct measurements of the critical temperature for failure can be undertaken.

Although it may seem an impossible task ever to be able to predict service performance accurately from a knowledge of laboratory test results, it is preferable to have such an aim in view and to work towards its fulfilment rather than to continue blindly applying the results of tests the physical significance of which is not fully understood.

Acknowledgment

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* Although the Four-ball Machine values are consistently lower than those of the Two-ball Machine, it is not considered that the general order of difference is significant or necessarily due to the difference in sliding conditions (Four-ball Machine, pure sliding: Two-ball Machine, sliding and rolling), since the method of estimating the values of critical temperature is an approximate one only. Difference between oils on any one machine may, however, be considered significant, since any errors in the assumptions will affect all estimates equally.

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ROAD AND LABORATORY WEAR TESTS OF GEAR OILS

By H. L. Bingham * and J. G. Withers * (Fellow)

Introduction

The importance of wear in the assessment of automotive gear lubricants is brought out in the full-scale axle tests of the U.S. Army Specification MIL-L-2105 for hypoid oils. However, in the development of additives and finished lubricating oils, and for routine quality control, it is desirable to have a much less expensive test procedure by which the relative wear characteristics of oils may be judged. Before such a test can be developed it is essential that there should be a background of information on service behaviour, preferably from road tests carried out under ordinary driving conditions. Published data are very limited, and for this reason the present programme has included the compilation of wear data from the back axles of vehicles operating on the road. The laboratory method presented, which shows a reasonable measure of correlation with the road data, must be considered as tentative only, since the work is still in progress. Many more road tests on an even wider range of lubricants will be necessary before it is possible to consider such a laboratory test as fully established.

Test Lubricants

These covered as wide a range as possible, so that the sensitivity of both methods of test could be ascertained.

A lubricant recommended by the car manufacturer was employed so that a necessary datum level of wear could be obtained. This was followed by a selection of other oils containing hypoid additives of known standards.

An additive meeting U.S. Federal Specification VV-L-761 was chosen as representative of high wear and those used in the preparation of U.S. MIL-L-2105 specification oils for data typical of current hypoid oils. Details of the oils and additives used are given in Table I.

* Sunbury Research Station, Anglo-Iranian Oil Co. Ltd.

TABLE I
Oils Used

Base oil	Hypoid additive	SAE classification	Test oil, reference No.
Marketed mild EP grade		140	1
2	A	140	2A
2	B	140	2B
Marketed hypoid grade		90	3
4	A	,,	4A
4	B	,,	4B
4	C	,,	4C
4	D	,,	4D
Pool 19	A	140	5A
Marketed hypoid grade		90	6

Base oils 2 and 4 were solvent refined products, their only difference being one of nominal viscosity. Where recommended, SAE 140 grades were used with spiral bevels and SAE 90 grades for hypoid axles.

Additive B meets the Federal Specification, additives C and D are employed in the production of MIL-L-2105 oils, and additive A is a MIL-L-2105 type subsequently replaced for commercial oil production purposes by additive C. All the oils were prepared with additive concentrations as specified by the additive manufacturers.

Pool 19 with additive A was used in conjunction with oil 2A to determine whether differences in the base oils could be detected in the tests. Both base oils were solvent refined types of the same nominal viscosity.

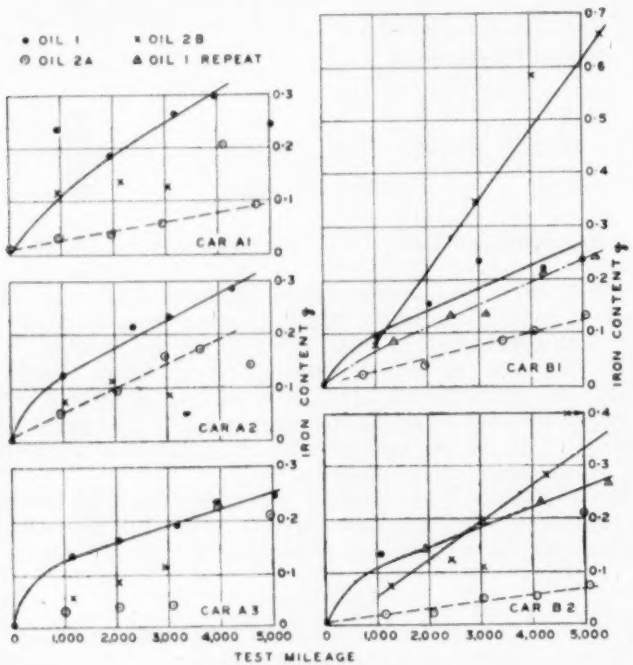
ROAD TESTS

Twelve post-war saloon cars of various popular makes were used. Details of the cars, together with relevant information on the back axles, are given in Table II.

TABLE II
Saloon Cars Used

Car reference No.	Year	R.A.C. rating, H.P.	Rear axle				
			Type	Ratio	Capacity, pt	Recommended lubricant	Recommended oil-change period, miles
A1	1948	14	Spiral bevel	4·78 : 1	4	SAE 140 EP	6,000
A2	,,	14	,, ,,	,,	,,	,,	,,
A3	,,	14	,, ,,	,,	,,	,,	,,
B1	,,	16	,, ,,	4·33 : 1	1¾	,,	5,000
B2	,,	16	,, ,,	,,	,,	,,	,,
C	1950	16	,, ,,	4·3 : 1	2½	SAE 90 EP	—
D	,,	18	,, ,,	4·125 : 1	3½	SAE 140 EP	10,000
E	1946	14	,, ,,	—	2½	,,	8,000
F	1950	10·6	,, ,,	5·14 : 1	2½	,,	5,000
G	,,	13·4	Hypoid	4·875 : 1	1½	SAE 90 Hypoid	6,000
H	,,	13	,,	,,	2	,,	10,000
J	,,	8	,,	4·55: 1	1½	,,	6,000

For the assessment of wear, measurement of the iron content of the used oil was considered to be the most practicable method; the axle tests were secondary to the main duties of the cars, and frequent dismantling of axles for examination purposes could not be permitted. The method used gives an indication of the wear of the axle as a whole, including not only the wear of the ring gear and pinion teeth but also that of the differential unit, shaft splines, and anti-friction bearings. It is believed, however, that most wear occurs at the mating surfaces of the teeth of the main



FIGS 1 and 2

WEAR TESTS OF GEAR OILS—ROAD TESTS

drive and that the results obtained can be taken as representative of the wear of these parts.

New cars were given a running-in period of between 1000 and 1500 miles before any tests were made; in the majority of cases, however, the car had completed many times this mileage. Test distances of 5000 miles were used, except for two cars, where the distances were 3000 miles. Sampling of the used oil from an axle was facilitated by fitting 2 BA auxiliary drain screws to the main drain plugs of the axles. Samples (2 oz) were taken at regular intervals throughout the tests, make-up oil being added after sampling so that the correct oil level was maintained. In all calculations of the iron content at the various periods, allowance was made for the loss of iron in the test charge due to sampling. The sampling

or draining after a test was carried out immediately after a run when the axle was warm.

The iron concentration of the samples was determined by normal analytical procedures. Special care was taken, however, in the mixing and in the settling time allowed for the sample before the analytical test was made, because it was observed that small particles of iron separated out from certain oils after standing, and when these were included in the iron

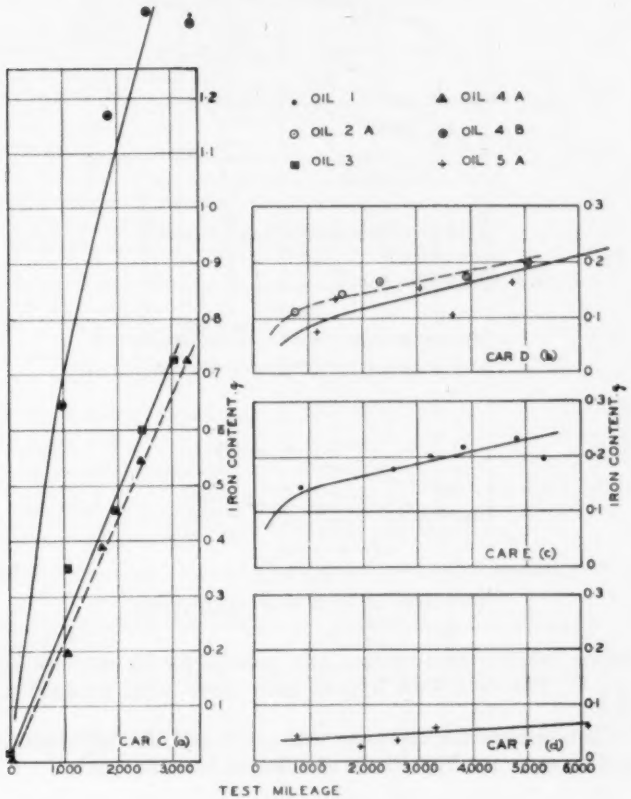


FIG 3

WEAR TESTS OF GEAR OILS—ROAD TESTS

analysis, stray high results, in excess of the usual trend of points, were given. Examination of the particles showed that they were of a flaky nature of a type associated with tooth-surface fatigue effects rather than the result of ordinary mechanical wear. Consideration of this led to the decision that the particles should be ignored and that the mixing and settling times of the samples should be fixed so that they would be eliminated by settling before the required amount of oil for the analysis was decanted.

The operation of the vehicles on the road was typical of ordinary driving; there were mixed conditions of traffic and open-country runs fully laden for vehicles A1, A2, and A3, duties of a taxi nature for cars B1 and B2, and a mixture of short-journey traffic runs and extensive open-country runs for the remaining cars.

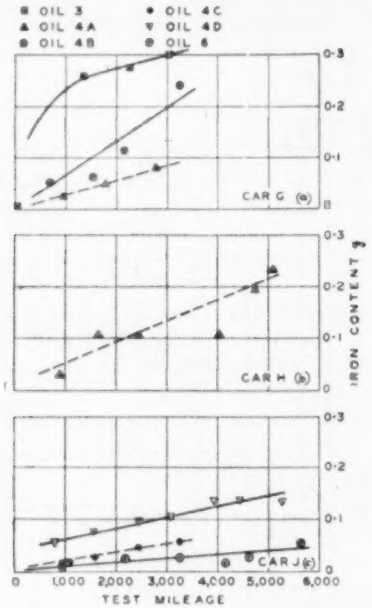


FIG 4

WEAR TESTS OF GEAR OILS—ROAD TESTS

The curves relating iron content and mileage for all cars are shown in Figs 1 to 4. The cars with hypoid axles have been grouped together in Fig 4.

Fig 2 includes repeatability tests with oil 1, and Fig 3(*b*) illustrates the differences between the hypoid oils of different base materials.

LABORATORY TESTS

The four-ball machine was used as a basis for the development of a test procedure. Details of the machine have been published elsewhere,* and only a brief description will be given here. The salient features are the simplicity of the test specimens—half-inch steel ball bearings—and the small amount of lubricant required for a test.

Four new balls are used in each test; three are clamped securely together in a cylindrical container (the ball pot) by means of a locking ring, and the fourth is pressed into a chuck which is fixed into the vertical spindle

* Boerlage, G. D. *Engineering*, 1933, **136**, 46.

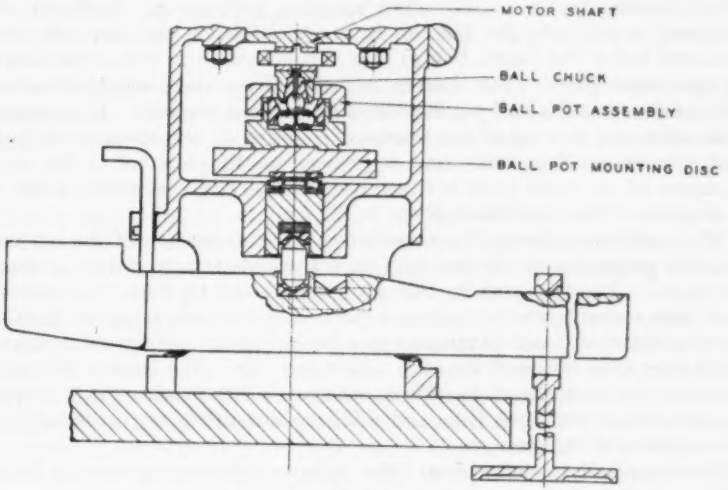


FIG 5

FOUR-BALL EP LUBRICANT TESTING MACHINE

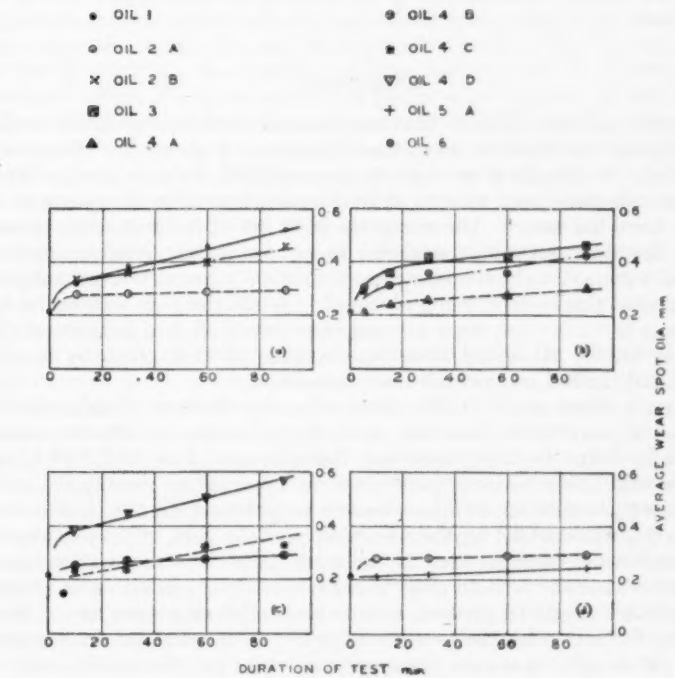


FIG 6

WEAR TESTS OF GEAR OILS—FOUR-BALL MACHINE

of the driving motor. This motor speed is 1500 r.p.m. Sufficient test lubricant is put into the ball pot to cover the balls, and the ball pot is mounted below the fourth ball so that this is located in the cavity formed by the other three. The system is loaded by a dead-weight-lever arm arranged so that the ball pot is pressed against the top ball. In operation, wear scars are formed at the points of contact on the three lower balls, and a corresponding wear ring is present on the top ball. The mean diameter of the wear scars is taken as a measure of the wear for the oil. A diagram of the machine is given in Fig 5.

The machine is designed primarily for the examination of the extreme-pressure properties of oils, and for this, a 1-minute test procedure is usually employed. For the work in this programme, the machine was operated as a wear tester in which a series of individual runs was made of durations varying between 5 and 90 minutes at a load of 15 kg. Wear/time relationships were thus obtained for each of the test oils. The load of 15 kg was chosen to ensure as far as possible smooth wear, with freedom from incipient seizure effects, for both base and additive-containing oils irrespective of the duration of the test.

The four-ball machine wear/time relationships are shown in Fig 6. The wear spot diameter given at zero time is the Hertz diameter, *i.e.*, the diameter of the circular impression at the points of contact of the balls due to the elastic deformation of the balls under the application of the 15-kg load.

Discussion

The road-test data indicate that iron content provides a sensitive method for assessing the relative wear characteristics of gear oils. Tests with oil 1 in car B1 (Fig 2) show that the repeatability is fairly good. Where the same oils have been used in different cars, the order of placing of the oils has been the same. The exception is oil 2B with the A series of cars; in this the data are not considered to be completely reliable, since an enforced termination of the test periods at 3000 miles prevented sufficient experimental points from being obtained. While the points given for this oil show a trend for less wear in comparison with oil 1, it is believed that the wear for oil 2B would have been similar to that given by cars B1 and B2 had the full test periods been completed.

The work illustrates that the choice of car or the type of axle, whether spiral or hypoid bevel, does not seriously influence the relative results. It must be borne in mind, however, that the use of an SAE 140 hypoid additive containing oil in a spiral bevel axle (excepting car C), *i.e.*, an oil much more powerful in extreme-pressure properties than the requirements of the axle, was decided by the availability of the cars. The experiments were made to determine wear of the steel parts, and no examination of the axles was made to determine the effect of these oils on parts of other materials that might be present, such as bronze bearing cages, etc. When, on a very few occasions, the presence of yellow metal particles was suspected in the oil samples, analysis for copper showed that the amount was insignificant, and suggested that they were the result of normal wear. The type of driving, again, does not appear to be critical, whether it is closely

controlled as in the heavy-duty tests for the A series of cars, or uncontrolled as in the transport conditions for cars B1 and B2, which were mainly on taxi-work.

The high wear given by car C is not typical of the average car judged in terms of the other tests, being many times the usual amount. This suggests tooth-loading conditions above the average; it is confirmed to some extent by the manufacturer's recommendation of an EP 90 grade of oil for the spiral-bevel axle.

If the data given for oil 2B in Fig 1 are ignored, the inferior wear characteristics of the Federal additive B are shown in all cases (Fig 2, car C, Fig 3, and car G, Fig 4), and the superiority of the oils containing additives A and C of the MIL-L-2105 type is clearly indicated.

When consideration is given to the evaluation of a wear rating from these curves so that a more direct comparison of the data may be given, a detailed examination shows that rate of wear is just as important as total wear. This is clearly illustrated by oils 1 and 3, which in almost every case, gave a relatively high rate of wear over the first 1000 miles or so, and thereafter a considerably reduced rate. Repeat tests made with these oils have shown the effect is a peculiarity of the oils, and it occurs irrespective of the type of oil in previous use. No explanation of this can be given, but the effect suggests that some form of conditioning of the axle or the oil takes place at the beginning of the test. In this connexion, experiments were made to determine whether any change in the four-ball wear/time characteristics was obtained after pre-heating the oil for 48 hr at 200° F (93·3° C), to simulate oil conditioning, and to investigate the corrosive effect, if any, on mild-steel plates when rotated at 600 r.p.m. in oil at 65° C for 50 hr. The temperature 200° F (93·3° C) was chosen arbitrarily, but as data on the bulk temperatures of the oil in the axles were accumulated during the road work, the temperature of 65° C for the second series of tests was chosen as representative of the average steady temperature reached in the axles on the road. In neither test, were the results conclusive; the pre-heated oil gave similar wear/time curves to the untreated oil, and the corrosive effect was negligible. In contrast to the behaviour of these two oils, the remainder gave a fairly constant rate of wear throughout their test periods.

In an assessment of the wear characteristics of these oils, total wear is obviously of main interest when definite oil-change periods are adhered to. But where recommended oil-change periods vary, some allowance for rate of wear, as mentioned previously, becomes necessary. Reference to Table II shows that recommended periods are between 5000 and 10,000 miles, dependent on the type of car; no relation is evident between these periods and the oil quantities in the axles. The practice of average users is not known, but it is believed that oil changes are made less frequently than recommended. With this in mind, and after consideration of the relative merits of total wear and rate of wear, as separate factors for rating purposes, it was decided that the total iron at 10,000 miles would provide the most useful criterion of oil behaviour. Values for the oils are given in Table III, which includes, for purposes of comparison, total iron at 5000 miles and rate of wear. In the evaluation of the total iron, the rate of wear, in grams per mile, was obtained from the best straight lines

through the points as determined by the method of least squares; total iron at the appropriate mileage was calculated from the equations thus obtained. To overcome certain anomalies caused by the high initial rates of wear of oils 1 and 3, the points at zero mileage, *i.e.*, the iron present in the unused oils, were ignored in all cases in this analysis. It will be observed that the use of 10,000 miles represents a wide extrapolation of the experimental data; no evidence was given, however, throughout the tests which indicated that any deviation from a linear-law relationship between wear and mileage would be present after steady wear conditions had been established.

An examination of the values of total iron at the two mileages for each oil in Table III shows that in only a few cases, most notably with oils containing additive B, is the total iron at 10,000 miles more than twice that at 5000 miles; this suggests that the rating at 5000 miles is the more severe of the two.

Except for two oils, the four-ball machine results are in fairly good agreement with the road tests. The exceptions are oils 2B and 4B, both containing the Federal specification additive, which give relatively low wear compared with the road-test data. The remaining oils are placed in the same order by the four-ball machine as given in the road tests. To assist comparison, the figure numbers of the four-ball machine curves and corresponding road test curves are :—

Four-ball Machine	Road Test
Fig 6(*a*)	Figs 1 and 2
„ 6(*b*)	„ 3(*a*) and 4(*a*)
„ 6(*c*)	Fig 4(*c*)
„ 6(*d*)	„ 3(*b*)

The sensitivities of both methods of test are well illustrated by oils 2A and 5A (Figs 6(*d*) and 3(*b*)) in which the only difference is in base material. While oil 2A is shown to give higher wear throughout the range of the tests, oil 5A gives a slightly higher final rate of wear in both cases.

It was anticipated that the oils containing the Federal specification additive would give more wear than the other oils in the four-ball machine work. To determine whether the relative wear characteristics of these oils were effected by load, tests were made at higher loads up to the limit of 50 kg, the critical load above which incipient seizure effects were present in the ball system with runs of the longest duration. No significant results were given by these tests.

As for the road tests, both rate of wear and total wear are significant when consideration is given to the evaluation of a wear rating. To obtain a rating similar to that determined for the road tests, an examination of the total wear at 60, 90 and 120 minutes was made. As before, the best straight lines through the experimental points were determined by the method of least squares. From this examination, the total wear at 90 minutes was chosen as being most representative of the oils. The values are given in Table III.

It was stated previously that the relative order in which the oils were placed by the road tests was generally the same irrespective of the car used. It will be noted, however, that the amount of wear for an oil at, say, either 5000 or 10,000 miles, varies according to the type of car in use. Because

of this, no direct approach to a more useful correlation between road and laboratory tests can be made. This difficulty in future tests will be over-

TABLE III

Values of Total Wear

Road Tests				
Car	Oil	Rate of wear, g/mile	Total wear, g at	
			5000 miles	10,000 miles
A1	1	0·000059	0·36	0·66
	2A	0·000033	0·15	0·32
	2B	—	—	—
A2	1	0·000048	0·33	0·57
	2A	0·000029	0·19	0·33
	2B	—	—	—
A3	1	0·000051	0·32	0·57
	2A	—	—	—
	2B	—	—	—
B1	1	0·000034	0·25	0·42
	2A	0·000027	0·13	0·26
	2B	0·00015	0·64	1·40
	1	0·000039	0·23	0·42
B2	1	0·000032	0·25	0·42
	2A	0·000014	0·071	0·14
	2B	0·000077	0·35	0·73
C	3	0·00020	1·11	2·11
	4A	0·00023	1·13	2·27
	4B	0·00033	2·07	3·70
D	2A	0·000017	0·20	0·29
	5A	0·000023	0·18	0·30
E	1	0·000016	0·22	0·30
F	5A	0·0000067	0·06	0·10
G	3	0·000031	0·31	0·46
	4A	0·000032	0·16	0·32
	4B	0·000080	0·36	0·76
H	4A	0·000039	0·20	0·40
J	4C	0·000020	0·10	0·20
	6	0·0000063	0·04	0·07
	4D	0·000021	0·15	0·25

Four-ball Machine		
Oil	Rate of wear, mm/min	Total wear at 90 min, mm
1	0·0024	0·52
2A	0·00019	0·30
2B	0·0016	0·46
3	0·0010	0·46
4A	0·0008	0·31
4B	0·0015	0·42
4C	0·0018	0·35
4D	0·0022	0·57
5A	0·00049	0·25
6	0·00039	0·29

come by the use of a reference oil, of a kind suitable for both spiral and hypoid bevels; a relative rating will then be obtained for each of the test oils, and the differences between cars, in relation to the amount of wear given for an oil, will be eliminated.

ACKNOWLEDGMENTS

The authors acknowledge the help and advice given by Mr B. W. Samuel in the determination of the iron contents of the oils and thank the chairman of the Anglo-Iranian Oil Company for permission to publish this paper.

PRODUCTION OF LUBRICANT TEST GEARS

By R. D. B. STONE *

THE lubricant test gears which are undoubtedly the most widely used in the United Kingdom, particularly by the oil companies, are the fifteen- and sixteen-tooth 5-DP gears for the IAE 3¼-inch centres machine, and it is to the production of these gears that the scope of this paper is limited.

It is the main object of the producer to provide test specimens of the highest possible degree of uniformity so that the failure loads of the gears under test can be repeated with reasonable consistency, thereby reducing to a minimum the number of tests necessary with a given lubricant in order to determine the mean failure load. Broadly speaking, the problems confronting the producer in his endeavour to achieve this can be placed in the following categories :—

(1) Material.
(2) Heat treatment.
(3) Dimensional accuracy.

The material for the test gears is chosen by the user according to the nature and purpose of the tests to be carried out, but it is the responsibility of the producer to obtain the material and to check that it conforms to specification, as well as to understand its properties so that it may be correctly processed. The two materials that have been, and still are, most commonly used are En.34 and En.39 steels, and En.34 predominates. It is not unreasonable to assume that the materials selected for test gears should be related to the materials used commercially for gears or like components for which the lubricants are being tested. In the very wide field of private and commercial vehicles quite a variety of gear steels are in use to-day. In the case of private cars, whilst a number of large manufacturers favour En.34, En.35, or En.36 steels for their gears, through-hardening En.18, En.24, and En.30 steels are also quite commonly employed. Again, in the case of commercial vehicles, although many manufacturers employ En.36 or En.39 in the light to medium range of vehicles, En.24 or En.30 are also used. In the aero-engine industry En.39 steel is also widely used on highly stressed gears. It would appear, therefore, that for case-hardening steels the present selection of materials for test gears is a perfectly reasonable one. The author is unaware of any

* The British Gear Grinding & Manufacturing Co. Ltd.

comprehensive tests carried out on the IAE machine using through-hardened test gears, or whether a satisfactory relationship has been determined between lubricants tested with case-hardened gears and their effect on, or suitability for, through-hardened gears.

As regards the type of gear blank used, it is generally assumed that gears made from upset forgings are the best, in view of the nature of the grain flow, and test gears are in fact normally made from upset forgings. However, it is interesting to note here the results of an investigation that MIRA carried out in 1949 on the effect of the type of blank on gear scuffing. A series of gears, some made from forgings and some cut from bar stock, each type showing its typical macrostructure, were subjected to normal scuffing tests, and also, in order to ascertain their respective resistances to pitting or tooth breakage, to high load tests. Whilst it was admitted that the investigation was a short one, it was concluded from the results obtained that, for oil rating tests, gears could as well be made from cut-off blanks as from forgings. These particular tests were made when there was considerable difficulty and delay in obtaining forgings, and it was hoped that bar material would be more readily obtainable. This did not prove to be the case, but it should be said that there has certainly been no improvement in the delivery position of either type of blank, irrespective of the steel specification, up to the present day.

Between the receipt of material and heat treatment, a number of standard and comparatively straightforward machining operations occur, such as turning, gear cutting, and drilling. The face width of the teeth has naturally to be closely controlled so that the tooth loading may be calculated, and also the central disposition of the teeth with respect to the overall width of the gear, as the gears are reversed on the test machine so that both sides of the teeth may be utilized. It is also important to ensure that the radius blending the gear teeth with the boss on either side is smooth and free from tool marks, in order that the tooth strength may not be impaired. These operations are, however, reasonably straightforward, and need not be enlarged upon. The next problem is heat treatment.

Variations in heat treatment resulting in differences in case microstructure can undoubtedly affect the scuffing load, and in this connexion reference is again made to the MIRA report of 1949 on "The effect of material and heat treatment on gear scuffing." Test gears in En.34 and En.36, which had a coarse martensitic case structure, gave considerably higher scuffing loads with an undoped oil than were obtained when similar gears were requenched and a finer-grained case structure obtained. The gears in En.34 had in the first instance been subject to a single-quench treatment. It will be agreed that a coarse martensitic case structure is not generally desirable, and it is our practice, in order to achieve uniformity and a fine-grain structure, to subject gears in En.34 as well as En.39 to a double-quench treatment. Again, with the object of uniformity and to ensure uniform heating and the best packing conditions, it is considered preferable to carburize the blanks in comparatively small quantities, the maximum number in a box being sixteen. Test pieces are inserted in the box with each batch so that the case depth can be checked and also the case structure examined from time to time. It is considered important to check regularly that an adequate depth of case is maintained, inasmuch as

the gears are normally re-ground once or even a second time after failure and used again.

Surface hardness can also affect scuffing loads, although there is some evidence to suggest that with steels of high nickel content, both case hardening and through hardening, an increase in hardness may be accompanied by a decrease in scuffing load. In the hardness ranges over 750 V.P.N., however, the differences in hardness are believed to be less critical and, therefore, producers aim at a minimum hardness of 750 V.P.N. on test gears.

After heat treatment there remain the final grinding operations which largely control the dimensional accuracy of the gears. As with the earlier operations of turning, etc., the grinding of bores, faces, and outside diameters are straightforward and routine operations, and it is only with the subject of tooth profile grinding that it is necessary to deal at greater length.

Gear-teeth can be ground by two distinct methods :—

(1) The generating system in which the effective portion of the grinding wheel can be likened to a rack tooth and in which a generating motion is imparted to the gear.

(2) The formed-wheel system in which the grinding wheel is trimmed to the required shape, and in which the relative movement between the grinding wheel and the gear is only that required to traverse the face width of the gear or to index from one tooth to the next.

It is not the purpose of this paper to discuss the relative merits of the two systems, but it is believed that the majority of test gears are ground by the formed-wheel system. This system is favoured by the author's company.

In order to explain our grinding technique reference must be made to earlier experiences on the grinding of highly stressed gears, particularly aero-engine gears. As a result of inspection of ground teeth by surface etching, it was learned many years ago how easy it was for excessive generation of heat during grinding to cause tempering or even, with the aid of the coolant, local rehardening. Whilst it will be acknowledged that grinding is accompanied by heat generation, it has not always been appreciated to what extent this heat can affect the material being ground. Having accepted that there were certain inherent dangers in grinding, it was found that, with the technique of grinding then in use, grinding abuse most frequently occurred on gears which had a particularly high surface finish. Although, however, some aero-engine manufacturers specified on certain gears the required surface finish in terms of micro-inches, others on gears performing similar functions did not. Therefore, a number of experiments were carried out in the cases where surface finish was not specified, and it was found that by using grinding wheels of coarser grit and softer grade than formerly, a much greater degree of freedom from grinding abuse was obtained. The changes effected were as follows :—

(1) 60 and 80 grit wheels replaced by wheels in 46 grit.
(2) K grade reduced to J or I grade.

The use of coarser grit wheels resulted naturally enough in a coarser

surface finish. As measured on a Talysurf instrument the surface roughness of gear-teeth ground with a 46 grit wheel was found to be

$$H_{av} = 22/26 \text{ micro-inches}$$

and

$$H_{max} = 80/100 \text{ micro-inches.}$$

This compared with a surface roughness of

$$H_{av} = 8/14 \text{ micro-inches}$$

and

$$H_{max} = 25/40 \text{ micro-inches}$$

on gears ground with 60 and 80 grit wheels.

Many thousands of highly stressed aero-engine gears have been ground with 46 grit wheels, with the resultant surface finish above-mentioned, and no evidence has been discovered to suggest that this degree of surface roughness has been in any way detrimental to the proper functioning of the gears. On the contrary, having examined many such gears after several hundred hours running, on which the original grinding lines were still clearly visible, the theory has been advanced that the coarser finish is in fact beneficial from a lubrication standpoint.

Results obtained by MIRA on a disk testing machine indicated that the scuffing load is higher between disks on which the finishing lines are parallel to the axis of the disk—as is the case with gears ground by the formed-wheel system—than between disks with finishing lines as produced by normal cylindrical grinding. It is known also that it was the practice of certain German aero-engine manufacturers to grind main reduction wheels by the formed-wheel system and mating pinions by the generating system, both systems giving an entirely different type of surface finish. Much has still to be learned about the effects of surface finish on gear lubrication and scuffing.

Reverting to test gears, it is logical, in the light of the foregoing remarks, to state that it is still our practice to-day to grind them with a 46 grit J grade wheel. It must not be implied that perfectly satisfactory gears cannot be and are not ground with much finer grit and harder grade wheels, but only that as the density of the grinding wheel increases with a reduction in grit size and an increase in hardness, so also does the danger of heat generation due to wheel loading.

In regard to the control of the involute profile, at present the permitted drawing tolerance on test gear profiles amounts to 0·0002 inch, and with the formed-wheel system the accuracy of this profile and its repeatability within this tolerance is governed largely by the master template and the pantographic or similar mechanism that transfers the required shape from the template to the grinding wheel. Of first importance to the producer, however, is his ability to check accurately the results obtained. It is, therefore, essential to maintain inspection equipment at the highest pitch of efficiency. Most involute testers incorporate a dial indicator gauge, and on the sensitivity of this gauge much can depend, particularly in the case of true involute gears where a true involute is represented by zero movement of the dial indicator pointer. There is a danger in such

cases that very small deviations from the involute will not be registered due to loss of sensitivity and inertia in the recording mechanism. This danger is present with lubricant test gears, which are true involute from the lowest active point of the tooth profile to the upper limit of the single-tooth contact zone. Constant checks must, therefore, be made with reference gears and by other means to ensure maximum sensitivity and accuracy.

It is by attention to such points as have been mentioned, and by close control by the inspection department at all stages of manufacture, that the most consistent and accurate test gears are produced.

Acknowledgments

The author's thanks are due to MIRA for the information gathered from their various reports and, as a gear producer, to the users of test gears, who, despite all the producer's care, destroy them with such ease and in such quantity.

THE TESTING AND PERFORMANCE OF LUBRICANTS FOR HIGH-SPEED GEARS

By J. Greenwood * and R. W. Morton *

Introduction

In the development of lubricants for application in high-speed gear trains, it is essential to have a suitable laboratory-scale screening test. A number of small test machines, such as the Falex (Cornell or Faville-Levally), Almen, SAE, Timken, Four-ball, disk machines, and IAE gear machine, have been proposed for this purpose. With the exception of the last-mentioned, all these test machines use a simple form of test piece which can be manufactured easily and cheaply with the object of improving test reproducibility. The use of these simple test pieces, however, makes the test less realistic in relation to practical conditions. The IAE gear machine uses simple gears which approach more nearly to practical conditions. Reproducibility of tests on this machine is, however, dependent upon the accuracy with which the gears can be made and operated. Whether it is possible to attain a satisfactory level of reproducibility with the IAE gear machine and the validity of results so obtained are discussed in the present paper.

The IAE 3¼-inch gear lubricant test machine [1] was originally developed by the Research Department of the Institution of Automobile Engineers for their investigations into automotive spur gears. In 1942 it was adapted to the testing of aviation engine oils in connexion with an urgent problem of aviation-engine reduction-gear lubrication, and a number of machines were later installed in the laboratories of the engine builders and the principal oil companies.

Although the gear lubrication problem on this particular engine has long

* Esso Development Co. Ltd.

since disappeared, gear test machines have proved extremely useful as laboratory tools in the investigation of many other lubrication problems.

Early work sponsored by the former Ministry of Aircraft Production in 1942–43 indicated that although the gear machine did not correlate with the Falex, SAE, Timken, or Four-ball machines, it was the only lubricant tester then available which gave reasonable agreement with aviation main-engine performance. The value of the IAE gear test machine has been confirmed by work described in this paper. In view of the fact that the other mechanical test machines have been fully described previously,[2] neither descriptions of, nor comparative results obtained on them are included in this paper.

The general conclusions given do not mean, however, that the gear machine is the only useful test machine; thus it seems probable that the SAE machine is more suitable for the testing of hypoid lubricants, and that the Four-ball machine is a very useful tester capable of evaluating a number of characteristics of lubricants. The Falex machine has advantages as a quick small-scale test, and the Timken machine appears to be similar in scope to the SAE machine. For applications in which the lubrication of high-speed gears is the critical factor, the IAE gear machine, as is shown in this paper, correlates extremely well with practice.

Experimental Results and Discussion

(a) *IAE Gear Machine Test Procedure*

The test procedure used throughout the majority of the work described in this paper is based on the conditions originally laid down by the MAP on the advice of the IAE Research Department (now MIRA), as those which appeared to give best correlation with main-engine performance. Two small changes have, however, been made. The lubricant supply rate has been standardized at 0·5 Imp. pint per minute, instead of a feed pressure of 6 p.s.i., in order to eliminate viscosity effects, and the actual test started at 10 lb lever load instead of 20 lb as used by the MAP. The other details of procedure are as follows.

One gallon of lubricant is circulated through a heater and pressure-control valve to the stationary gears at a feed temperature of 90° C, the latter being fairly representative of practical conditions. After circulating for about 1 hr to allow the temperatures throughout the machine to reach equilibrium, a lever load of 10 lb is applied and the gears run for 5 minutes at 2000 r.p.m. The machine is then stopped for 5 minutes during which the gears are inspected, the load increased by 5 lb, and running then resumed. This procedure is then repeated with further load increments of 5 lb until failure occurs, the normal criterion of failure being scuffing. This is usually indicated by a change in the pitch of the note emitted by the gears, an increase in the current taken by the driving motor, smoke in the test gear-box, and an increase in the temperature of the oil spray from the gears.

(b) *The Significance of Results obtained in Standard Tests*

Preliminary work indicated that, although some batches of gears were satisfactory, overall differences in mean failure load and variability between

different batches of gears frequently exceeded differences between different lubricants. Discussions were therefore held with three gear manufacturers in an endeavour to obtain test gears of improved quality. A test programme was then initiated using groups of En.34 and En.39 steel gears (for composition, see Table I) from each manufacturer with each of several lubricants in order to obtain information regarding the repeatability of the test. The tests were to be repeated after once, and if possible twice, regrinding the gears. In this way it was hoped that it would be possible to control the tests sufficiently to assess the effect of regrinding on failure load and variability while controlling the effects of difference between gears. This programme, which owing to the pressure of other work had to be combined with routine inspection work, is not yet complete, but sufficient data are available for useful conclusions to be drawn in the case of new gears, and for indications to be noted on the effect of regrinding.

TABLE I

Specifications for BS En.34 *and BS* En.39 *Steels*

	BS En.34 steel	BS En.39 steel
Chemical Composition, per cent		
Carbon	0·14–0·20	0·12–0·18
Silicon	0·10–0·35	0·10–0·35
Manganese	0·30–0·60	0·50 max
Nickel	1·50–2·00	3·80–4·50
Molybdenum	0·20–0·30	0·15–0·35
Sulphur	0·05 max	0·05 max
Phosphorus	0·05 max	0·05 max
Chromium	Nil	1·00–1·40
Heat treatment		
Blank carburize	880°–930° C	880°–930° C
Refine	850°–880° C *	850°–880° C †
Harden (in oil)	760°–780° C	760°–780° C
Temper	—	200° C max
Ultimate tensile stress	45 tons/sq. in.	85 tons/sq. in.
Elongation	18% min	12% min
Izod impact value	40 ft.lb. (min)	25 ft.lb. (min)

* Cool in air, oil, or water. † Cool in air, or quench in oil.

Pending delivery of the gears for the tests described above, the gear machines had to be operated on any available gears, thus giving corresponding data for tests in which no attempt was made to control variables due to gears.

In analysing the results, about 400 tests on ten lubricants were considered, some of these being controlled and some uncontrolled tests. Of these results only thirty-nine were rejected owing to the usual criterion of failure, namely scuffing, being absent. All of these were in uncontrolled tests which had to be stopped owing to wear, scoring, chipping, or breakup of the gears. All the results considered therefore refer to tests in which failure was by scuffing.

Analysis showed that the test is undoubtedly sensitive to the condition of the machine and the skill of the operator; breakdown of results to determine the effects of the different operators and machines was, however, not

practicable, but frequency/failure load graphs prepared from time to time have suggested that there have been no significant differences between the ratings given by the two machines during these tests. The results discussed do not refer exclusively to either repeatability or reproducibility, as a large proportion were obtained by one operator on one machine.

Before proceeding to analyse data generally, seventy-nine results obtained in controlled tests on one batch each of a mineral oil and a synthetic lubricant with three types of gears were examined to assess the variations between gears of any one type. In the tests the variability from one side of a gear pair to any side of any gear pair (including the other side of the same pair) was 28 per cent greater than between the two sides of one pair, as shown by the results in Table II. This variability is low

TABLE II

Variability of Single Tests (Standard Deviation in lb)

All tests carried out on one batch of each lubricant

Gear			Lubricant			
			Mineral oil J		Synthetic lubricant A	
Manufacturer	Steel	Condition	Side to side	All sides	Side to side	All sides
Y	En.34	N	3·6	5·2	7·2	4·3
		R	—	—	6·1	4·1
		Total	3·6	5·2	6·2	6·5
Y	En.39	N	3·7	5·2	5·9	8·7
		R	—	—	2·1	5·9
		Total	3·7	5·2	5·2	7·3
Z	En.39	N	—	4·7	—	2·1

N = new. R = reground once.

enough to suggest that there may be no real difference between the failure loads obtained on opposite sides of the same pair of gears, or any side of any pair, as a 28 per cent greater deviation might occur by pure chance once in every ten trials of this size. As a result of this, the main analysis was carried out ignoring whether results were obtained on the two sides of one pair of gears or on two or more separate pairs of gears.

(c) *The Effect of Gear Steel, Manufacturer, and Regrinding on Variability and Mean Failure Load*

The results of all tests, controlled and uncontrolled, are analysed in Table III, from which it will be seen that the variability obtained depends on the gear steel and manufacturer, but appears to be independent of the type of lubricant tested: further, from the data available, the standard deviation appears to be independent of the failure load of the lubricant. Thus En.39 gears manufactured by Z when used with lubricant A gave a

standard deviation of 1·7 lb, compared with 2·1 to 3·5 lb, for En.39X gears with lubricants A and C, and En.34Y gears with lubricant C. Statistical analysis shows these standard deviations to be significantly different from the remainder of the data in the table, which gave a mean standard deviation of 5·7 lb. A limited amount of data obtained with a mineral oil of 35 lb failure load (not shown in the table) also gave a standard deviation of

TABLE III

Variability of Gears (Standard Deviation in lb)

Lubricant batch effects eliminated

Gear	Synthetic lubricants			Mineral oils		All results
	A	B	C	J	K	
34X	3·5 (13) [a]	6·3 (5)	2·1 (7) [a]	—	5·3 (4)	4·3 (29)
39X	3·5 (2)	6·8 (3)	—	—	5·1 (5)	7·0 (10)
34Y	7·0 (25)	4·0 (7)	2·5 (7) [a]	6·2 (10)	10·0 (2)	6·2 (51)
39Y	7·3 (20)	—	3·6 (3)	8·0 (12)	3·6 (1)	7·2 (36)
39Z	1·7 (11) [b]	—	—	4·8 (13)	—	3·8 (24) [a]
Mean failure load (lb) using En.34Y gears	100	110	110	95	50	—

[a] 1·0% level of significance compared with the remainder of the data.
[b] 0·1% level of significance compared with the remainder of the data.

The numbers in parentheses are the degrees of freedom, *i.e.*, number of observations minus the total number of groups (batch and regrinding).

X, Y, and Z indicate the gear manufacturers.

this order (7 lb). It is noteworthy that the variability obtained appears generally to be more characteristic of the manufacturer than of the gear steel, and that with the exception of En.39Z, several different batches of gears were used in each case. A delivery of En.34X gears since this analysis has, however, given exceptionally high failure loads and variability indicating that unfortunately the results for En.34X in Table III are not truly representative of the variations possible between batches of these gears.

A breakdown of the results to show the effect of the condition of the gears is given in Table IV, and indicates that, overall, gears manufactured by X appear to give no real difference in variability after regrinding, whereas those manufactured by Y appear to be less variable after regrinding once. The average failure loads of the different lubricants with all types of gears, new, once reground, and twice reground, are given in Table V, together with the number of observations. Comparison of the results obtained on En.34 and En.39 gears shows that those manufactured by X are again very similar in performance, but that appreciable differences exist between those manufactured by Y, whose En.34 gears give a mean failure load which is generally 15 to 25 lb higher than that obtained with En.39 gears. Similar differences exist between the failure loads obtained with En.39 gears from the three suppliers, although in this case insufficient data are available to allow estimates of the differences to be made. Generally, however, En.39X gears gave the highest failure load, and En.39Y

the lowest. All these differences appear to be independent of the failure load and the type of lubricant.

TABLE IV

Effect of Regrinding on Variability (Standard Deviation in lb)

Lubricant batch effects eliminated

Gear	Condition	Lubricant			
		A	B	C	K
En.34X	N	4·2 (5)	5·0 (3)	2·1 (7)	3·5 (1)
	R	2·8 (7)	7·9 (2)	—	—
	RR	3·5 (1)	—	—	5·8 (3)
En.39X	N	3·5 (2)	6·6 (2)	—	—
	R	—	7·1 (1)	—	—
En.34Y	N	7·6 (20)	4·5 (5)	2·7 (5)	—
	R	4·1 (5)	2·5 (2)	1·8 (2)	—
En.39Y	N	7·7 (15)	—	3·5 (3)	—
	R	5·9 (5)	—	—	—

N = New. R = Reground once. RR = Reground twice.
The numbers in parentheses indicate the number of degrees of freedom.
X and Y indicate the gear manufacturers.

TABLE V

Average Failure Load (lb) at 90° C

New, once reground and twice reground gears

Lubricant	34X	34Y	39X	39Y	39Z
A	104 (27)	99 (36)	93 (15)	70 (24)	77 (14)
B	108 (23)	110 (16)	103 (26)	—	—
C	109 (13)	110 (15)	—	91 (7)	—
D	82 (4)	—	73 (6)	—	—
E	100 (4)	104 (7)	—	78 (3)	82 (2)
F	—	70 (4)	48 (3)	—	—
G	62 (3)	65 (2)	64 (10)	50 (2)	—
J	—	96 (12)	—	69 (14)	79 (14)
K	59 (8)	48 (4)	40 (8)	42 (2)	—

The numbers in parentheses denote the number of observations.
X, Y, and Z indicate the gear manufacturers.

There appears, therefore, to be no such thing as a " mean gear machine failure load," unless in reporting results the gear steel and manufacturer are specified; or, since the relative ratings appear to be independent of gear steel and manufacturer, the failure load could be expressed as a percentage of that of a suitable reference oil.

Considering now the effect of regrinding on mean failure load, it will be seen from Table VI that this varies with the lubricant tested, and the gear steel and manufacturer, but that, within the limits of the data available so far, the overall effect is negligible, as regrinding in some cases increases the mean failure load by up to 13 lb, and in other cases decreases it by up to

TABLE VI

Effect of Regrinding on Average Failure Load

Gear		A	B	C	K
En.34X	New	98 (11)	111 (12)	109 (13)	—
	Reground	108 (12)	107 (11)	—	55 (3)
	Twice reground	109 (4)	—	—	62 (5)
En.39X	New	95 (8)	103 (16)	—	40 (8)
	Reground	92 (6)	105 (9)	—	—
	Twice reground	95 (1)	95 (1)	—	—
En.34Y	New	99 (30)	109 (12)	108 (11)	48 (4)
	Reground	92 (6)	114 (4)	118 (4)	—
	Twice reground	—	—	—	—
En.39Y	New	70 (18)	—	91 (7)	42 (2)
	Reground	71 (6)	—	—	—
	Twice reground	—	—	—	—

Numbers in parentheses denote number of observations.
X and Y indicate the gear manufacturers.

16 lb. In view of the number of variables present in these tests, statistical significance tests do not have much meaning, and no definite conclusion can be reached until the results of more controlled tests are available. Preliminary data from such tests are summarized below :—

Gears	Lubricant	Average failure load, lb: New	Average failure load, lb: Reground once	Standard deviation (new and reground)
En.34Y	A	101	92	4·1
En.39Y	A	71	71	7·0
En.34Y	J	98	87	4·2
En.39Y	J	68	62	3·6

It will be seen that in three out of four cases a significant drop in average failure load takes place on regrinding once; in the fourth case the general variability is higher.

Even including all the variables inherent in the main analyses considered above, the following product quality control limits can be set in terms of the number of tests :—

	1 in 20 limit	1 in 500 limit
For one test	±20 lb	±30 lb
For average of two tests	±14 lb	±21 lb
For average of three tests	±12 lb	±18 lb

Summarizing, then, it seems reasonable to conclude that the variability of the results obtained on the two gear machines at Esso European Laboratories is encouragingly small, and that by controlling test-gear quality, employing only skilled operators, and enforcing a high standard of maintenance, the variability of the results can be reduced still farther.

(d) *The Effect of Variables on the IAE Gear Machine Failure Load*
Lubricant Supply Rate

Tests have been carried out to study the effect of the rate of supply of test lubricant on the IAE gear machine failure load, using oil to specifica-

tion DED2472 B/O. The results summarized below indicate that variations in the flow rate from 0·25 to 1·0 pint/minute have no significant effect on the failure load obtained using En.39X gears.

Flow rate (pint per min)	Average failure load (lb)
0·25	76
0·50	75
1·00	81

Speed

Comparative tests at 2000 and 4000 r.p.m. on mineral oils and synthetic lubricants (Fig 1) have indicated that the failure loads of lubricants at

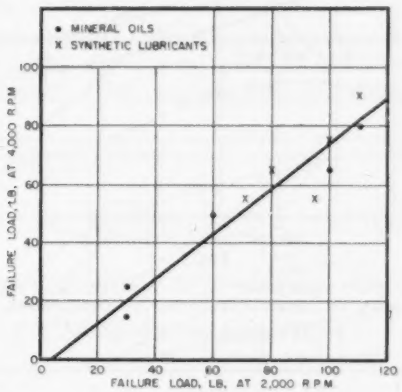


FIG 1

COMPARISON OF IAE GEAR MACHINE FAILURE LOADS AT 2000 AND 4000 R.P.M.
En.34Y steel gears used throughout

4000 r.p.m. are approximately 70 per cent of those at 2000 r.p.m., and that the relative ratings remain unchanged, at least in the case of these two types of lubricants. Tests at other speeds are being carried out, but insufficient data are available at present.

Lubricant Supply Temperature

In view of the wide range of operating temperatures encountered by lubricants in engines it was considered inadvisable to forecast performance from the standard failure load at a lubricant supply temperature of 90° C only. Tests have therefore been carried out at feed temperatures ranging from −10° to +100° C in order to check the performance of different types of lubricants, and the results are shown graphically in Figs 2 and 3. It will be seen from Fig 2 that the characteristic shape of the curve obtained varies with the type of oil tested, synthetic lubricants A, D, and E giving curves which are concave upwards, and mineral oils J and K curves which are sigmoidal in character. The dotted line gives the corresponding curve for mineral oil K containing 1 per cent of a mild extreme-pressure additive, P. Comparison of this with the curve for oil K itself shows that the increase in failure load imparted by the EP additive decreases with

increasing temperature until at temperatures above 150° C the additive becomes ineffective. Other tests at feed temperatures of −10° to 100° C

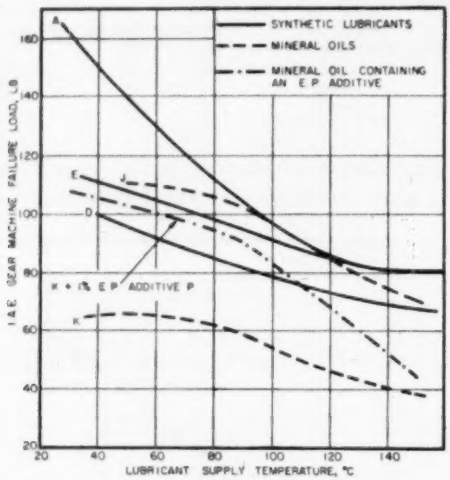


FIG 2

THE EFFECT OF FEED TEMPERATURE ON THE IAE GEAR MACHINE FAILURE LOAD OF DIFFERENT TYPES OF LUBRICANTS

En.34Y gears used throughout

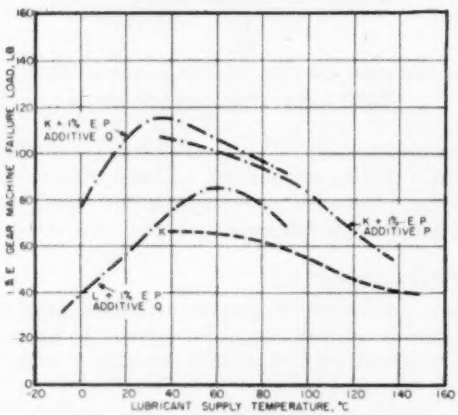


FIG 3

THE EFFECT OF FEED TEMPERATURE ON THE IAE GEAR MACHINE FAILURE LOAD OF MINERAL OILS CONTAINING EP ADDITIVES

En.39X gears used for K + additive Q and L + additive Q
En.34Y gears used for K and K + additive P

(Fig 3) on lubricants containing another mild EP additive, Q, have indicated that the effect of the additive decreases rapidly at temperatures below 40° to 60° C, becoming negligible below about 0° C. Unfortunately compara-

tive data for oils K and L at feed temperatures of 0° to 40° C are not available from this series of tests, but prior experience has indicated that the changes in failure load obtained over this temperature range are much smaller than in the case of the additive-containing oils. It thus seems probable that the range 0° to 150° C represents the limits of action of this particular type of additive.

These results are, of course, not applicable to all EP additives, but have been selected to indicate the importance of testing oils containing additives over the range of temperatures at which they are likely to operate in service.

Lubricant Viscosity

It has been suggested that there is an approximately linear relationship between the failure load of a mineral lubricant and its viscosity at a given operating temperature. This applies only to additive-free lubricants

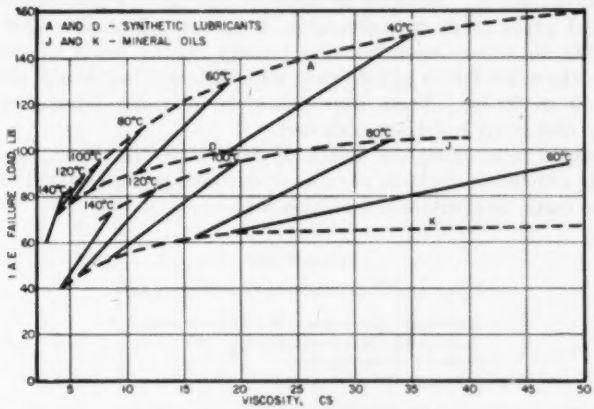


FIG 4

THE EFFECT OF TEMPERATURE AND VISCOSITY ON THE FAILURE LOAD OF MINERAL OILS AND SYNTHETIC LUBRICANTS

En.34Y gears used throughout

and, further, non-petroleum lubricants give lines of which the slopes are characteristic of the lubricant class. As indicated in Fig 4, the slope of the line also varies with the operating temperature. This figure was obtained by cross-plotting the data on oils A, D, J, and K from Fig 2; the broken lines are the result of joining the appropriate points obtained at different temperatures for these oils.

(e) *Endurance Tests*

A general criticism of mechanical tests for assessing load-carrying ability is that they are normally of relatively short duration. Thus, a lubricant may have a high scuffing load in a test rig, but prove to be unsatisfactory on prolonged running at lower loads, owing to fatigue failure of gear-teeth.

Exploratory work has therefore been carried out on the gear machines using En.39X gears in attempts to assess differences between lubricants on prolonged running at one load.

Early work indicated that the most promising method was to operate as in the standard failure load test up to the chosen load, and then to run continuously at this load until failure of the gears by scuffing, scoring, wear, or pitting occurred. The machine was stopped at 2-hr intervals for examination of the gear-teeth, and then restarted at the endurance test load.

The majority of the earlier tests were run at 50 to 60 per cent of the failure load of the lubricant, but it was later found that this usually gave an endurance life of the order of 200 hr, this being inconveniently long. Comparative tests were therefore run on a number of lubricants at a series of loads, using the same batch of gears, to discover whether a useful but shorter test could be devised. This work indicated that endurance tests at, say, 80 lb lever load on lubricants of adequate failure load would be of convenient duration. Analysis of tests carried out on different batches of En.39 steel gears from manufacturer X showed, however, that the endurance life obtained depended very greatly on the batch of gears used; results on the same batch of lubricant with different batches of gears varying from 0 to 50 hr. Tests were therefore suspended until sufficiently consistent test gears had been obtained.

Exploratory tests using one batch of gears have indicated, however, an interesting difference in the behaviour of extreme-pressure additives during endurance tests, as illustrated in Table VII.

TABLE VII

Effect of EP Additives on Endurance Life

Lubricant flow rate : 0·5 Imp. pint/min
Lubricant feed temperature : 90° C
Speed : 2000 r.p.m.
BS En.39X steel gears

	Failure load	Endurance life	
	lb	lb	hr
Oil H	130	85	4
		50	116
Oil H + 1% additive P	over 160	80	8
		50	41½
Oil L	35	—	—
Oil L + 1·4% additive P	93	55	105
Oil L + 1% additive Q	60	55	165

It will be seen that addition of 1 per cent of EP additive P to oil H increases the failure load appreciably, but appears to decrease the endurance life considerably. Similarly, comparison of the performance of EP additives P and Q in oil L indicates that the latter additive combines much lower failure load with appreciably greater endurance life at 55 lb lever load.

Practical Significance of Gear Machine Results

A frequent criticism of the IAE gear machine is that its standard test speed (2000 r.p.m.) is too low for the results obtained to have much value in assessing performance in high-speed gear trains as used in practice Nevertheless, this machine was considered to be the most useful test rig available for screening tests on lubricants. The results of full-scale tests have largely refuted the above criticism, as is shown by the results following.

High-speed Gear Rig

The failure loads of two mineral oils and six synthetic lubricants on the IAE gear machine at 2000 r.p.m. are compared in Fig 5 with those obtained

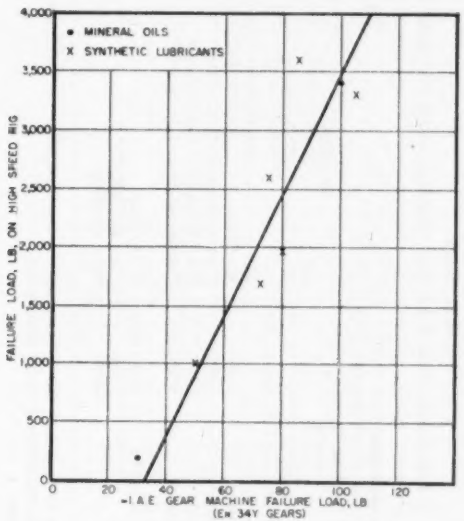


Fig 5

CORRELATION OF IAE AND HIGH SPEED (10,000 R.P.M.) GEAR RIG RESULTS

on a large high-speed (10,000 r.p.m.) gear rig. It will be seen that the relationship appears to be linear, and that reasonable agreement is obtained between the two machines, particularly when allowance is made for the repeatability of the tests (average about ± 10 per cent in the case of the high-speed rig).

Full-scale Reduction Gear-box Tests

Screening tests on the IAE gear machines at 2000 r.p.m. indicated that synthetic lubricant A was slightly superior in load-carrying ability to mineral oil J, and check tests to destruction were subsequently carried out on a full-scale reduction gear-box (main shaft speed approx. 20,000 r.p.m.). The results obtained were complicated by the number of other variables investigated, but the general conclusion, volunteered by the manufacturers,

TABLE VIII

Comparative Performance of Lubricants in the IAE Gear Machine and a Full-scale Reduction Gear-box

Lubricant	Lubricant feed temperature, °C	Reduction gear-box tests (approx. 20,000 r.p.m.) Tooth loading lb/inch face width		Result	IAE gear machine (2000 r.p.m.) tooth loading at failure (B), lb/inch face width *	IAE failure load as per cent of L.S. train tooth loading $\left(\frac{100A}{B}\right)$
		H.S. train	L.S. train (A)			
Synthetic lubricant A	50	4020	7560	No failure	8540	88·6
	70	3120	5900	Partial scuff in H.S. train	7200	82
	70	3610	6770	Partial scuff in both trains	7200	94
	90	2170	4080	Partial scuff in L.S. train [1]	6100	67
Mineral oil J	70	3120 max	5900 max	No failure	6600	89·5
	80	—	5460	Fine spalling [2]	6400	85
	120	—	4420	Fine spalling [2]	5200	85

[1] After completion of this test the lubricant jets were found to be partially blocked.
[2] These failures are considered to be borderline.
* En.34Y steel gears.

TABLE IX

Comparison with Main Engine Performance

Lubricant	K.V. cs at 210° F	IAE gear machine failure load (lb) *	Engine R	Engine S	Engine T
Mineral oil L	3·2	35	Unsatisfactory	Unsatisfactory	Unsatisfactory
Mineral oil K	9·0	50	Borderline	Unsatisfactory	Unsatisfactory
Mineral oil K + EP additive	9·0	90	Satisfactory	Satisfactory	Borderline
Mineral oil J	20·0	95	Satisfactory	Satisfactory	Satisfactory
Synthetic lubricant A	7·9	100	Satisfactory	Satisfactory	Satisfactory

* En.34Y steel gears.

confirmed predictions made from standard IAE gear-machine tests. Typical results are given in Table VIII, from which it will be seen that, at least in the case of these two lubricants, there appears to be a reasonable degree of correlation between the two machines at all oil-feed temperatures used.

Main Engine Performance

The performance of a number of lubricants in the IAE gear machine, and in main engines in which gear lubrication is the limiting factor, are compared in Table IX. It will be seen that the IAE gear machine gives reasonable agreement with main engine performance and that the results confirm the earlier conclusion of the MAP based on more limited data.

Thus for satisfactory operation the three engines considered in Table IX appear to require a lubricant of 90 to 95 lb minimum IAE gear machine failure load, irrespective of its viscosity. In two cases this can be achieved by adding an extreme-pressure additive to a mineral oil of medium viscosity, or by using a synthetic lubricant of appreciably lower viscosity, but higher failure load. The third case (engine T) is even more critical, requiring either the synthetic lubricant A or a mineral oil having 150 per cent greater viscosity at 210° F.

Conclusions

It may therefore be concluded that the IAE gear machine is a very valuable laboratory rig for the testing of either mineral or synthetic type lubricants for applications such as those in which the most critical features are high-speed heavily loaded gears, and there appears to be a good deal of justification for adopting this as a standard test method.

The work described, although incomplete, permits the following detailed conclusions to be drawn :—

1. Given careful control of test gear quality, gear effects can be reduced sufficiently to enable standard deviations of the order of 3 to 6 lb to be obtained in standard failure load tests. A high standard of maintenance and employment of skilled operators are necessary to achieve such repeatability.
2. The results of IAE gear-machine tests correlate well with those of tests on larger and more expensive gear rigs operating at much higher speeds.
3. Performance in main engines can be forecast, at least qualitatively, in cases in which gear lubrication is the critical factor.
4. The significance of endurance test results has been limited by test gear quality, but further work on this aspect appears to be justified.

Acknowledgments

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DEVELOPMENTS IN THE SPECIFICATION AND TESTING OF LUBRICANTS FOR HYPOID AXLES WITH PARTICULAR REFERENCE TO A FULL-SCALE BRITISH TEST PROCEDURE

By A. Towle *

Introduction

For many years British lubrication technologists have been toying with the idea of an equivalent crankcase lubricating oil series of tests to the 2-104 series standardized by the American Army Ordnance and now generally accepted by oil companies and Ordnance departments throughout a large part of the world as a universal test specification. Some progress has been made in the U.K. by the setting up of a British Lubricants Advisory Panel and the adoption of an equivalent British Specification, DEF/2101. The ideal, however, of testing British crankcase oils on British engines, and at the same time obtaining correlation with the accepted American standards as yet remains far from realized.

This paper deals with a British developed test procedure using British axles which has already been shown to correlate with the American 2-105B Universal Gear Lubricant test specification under high-torque conditions, and which the American Army Ordnance Reviewing Committee has already indicated will be acceptable to them as an alternative to their own test specification. Brief descriptions are given also of high-speed and moisture corrosion tests for universal gear oils using the same British axles, which tests it is believed will correlate with the corresponding American procedures and consequently also be acceptable by the American Army Ordnance.

Developments in the Use of Hypoid Axles

To realize why the popularity of the hypoid axle has increased so much in recent years the advantages to be gained by its use must be considered. These are twofold : (1) a lowering of the propeller-shaft line by an amount depending on the pinion offset, thus permitting the abolition of the propeller-shaft tunnel and giving a level floor in the rear compartment; (2) a general reduction in size and weight of the axle assembly made possible by the increased mechanical strength of the hypoid gear as compared with its spiral-bevel counterpart. Thus, there are several known cases where a change over to hypoid oils has enabled a reduction of one-third in ring-gear diameter to be achieved.

These advantages are not made possible without the disadvantage of

* Anglamol Ltd.

more difficult lubrication brought about by the increased sliding velocity in the case of the hypoid as compared with the spiral-bevel gears. In the latter case the velocity of sliding of the pinion is zero at the pitch line, but for the hypoid pinion the velocity of sliding does not reach zero anywhere, and is everywhere greater than that in the spiral-bevel pinion. This increased sliding velocity is due to the offset of the pinion, by which the hypoid gear is somewhat midway between the condition of a spiral bevel and a worm gear. The limiting temperature at which surface distress of the teeth first occurs depends upon the product of compressive stress (which in turn depends upon the relative radii of curvature of the hypoid teeth) and sliding velocity, and the surface temperature is influenced also by the degree to which the surfaces can be cooled in the interval between successive periods of contact. This cooling is naturally greatest with low-viscosity oils which, however, are probably more prone to give fatigue types of failure such as pitting and spalling. The problem of satisfactory lubrication of hypoid gears is therefore a complicated one, since the lubricant as to act (*a*) as a coolant, (*b*) as a chemical agent for building up an anti-welding film, and (*c*) as an oily film separating two rubbing surfaces, and the efficiency of the lubricant in performing these three services determines to a large extent the minimum size of axle and the permissible offset, provided the designer does his part in eliminating excessive deflection in the pinion mountings and in the axle casing. Nevertheless, the lubricating-oil industry has tackled the problem of lubricating hypoid gears, and to-day it is true to say that provided the mechanical considerations are correct, there is no longer difficulty in providing effective lubrication for this type of gear under any condition. As with other sides of automobile development, with improvements in metallurgy there will be a tendency for a further reduction in size of the gear unit, and this once again will throw the onus on the oil industry.

The first hypoid gears are stated to have been used in the U.S.A. in 1925, and from that date were developed by Packard in particular, until in 1937 thirteen makes of car in the U.S.A. are stated to have been using that type of gear. In the U.K., as far as the author knows, the first recorded use of the hypoid gear in a production car was in the 8-litre Bentley of 1929, and it was not until 1934 that further models appeared using this type of gear, this time the car being the 3½-litre Bentley manufactured by Rolls-Royce. Up to the outbreak of war there was little further increase in the hypoid axle's popularity, but with the introduction of new models in the immediate post-war period it was adopted by Jowett, Jaguar, Armstrong Siddeley, and Alvis—all in relatively small-scale production. The first company of the "Big Six" to change was the Standard Motor Company, with the introduction of the Vanguard and Triumph in 1948, followed by Morris, Austin (Sheerline and Princess only), Rootes (Hawk only), and finally by Ford on its new Consul and Zephyr in late 1950, and Vauxhall in the middle of 1951. In the 1951 Motor Show ninety-nine models listed in the *Autocar* Buyers' Guide were equipped with hypoid axles as compared with forty-one with spiral bevel, whereas a year previously the popularity of the two types was about even. It is therefore safe to assume that as time goes on the spiral-bevel type of axle will almost, if not quite, disappear from current production.

Some Requirements of a Hypoid Lubricant

The basic requirements of a universal hypoid oil may broadly be classified under the following headings :—

(1) Effective load-carrying capacity under all conditions.
(2) Ability to minimize wear.
(3) Stability.
(4) Ability to prevent corrosive attack on the axle components.
(5) Compatibility with other hypoid oils.
(6) Low foaming and channelling tendencies.

Effective Load-carrying Capacity

For a universal oil, conditions will vary between the high-torque, low-speed condition of an Army truck, farm vehicle, or sporting-trials car attempting to extricate itself from mud, to the high-speed low-torque condition of a racing car on the overrun. Under both these extremes and under all intermediate conditions the oil must possess sufficient load-carrying capacity to prevent failure of the gear-teeth by scuffing, rippling, ridging, or other interference with the manufactured profile of the teeth. The most severe condition may in practice occur while the gears are new and before the teeth have had a chance to condition themselves by running in.

Ability to Minimize Wear of Gears and Bearings

Obviously one of the primary requirements of an oil is to prevent serious wear of the gear-teeth under the exacting conditions of operation, but with hypoid gears there is an additional factor which must be taken into account. The pinion of almost all present-day hypoid axles is located in position by two taper roller bearings mounted back to back and spaced an inch or more apart. It is general practice to " preload " these bearings one against the other to give positive location of the pinion, and consequently to more positively locate the point of contact of the teeth under all operating loads. Wear on the ends of the rollers and the inner race lips results in loss in preload, displacement of the point of tooth contact, and a noisy axle. The process of wear is cumulative, since particles from initial wear have an immediate abrasive action, resulting in a further increase in the rate of wear, etc. While wear of both gear-teeth and pinion bearings is influenced by many mechanical factors, the properties of the lubricating oil have an appreciable effect on the rate of wear, and some oils which have a higher load-carrying capacity, by virtue of their higher activity also show the highest wear rate. It is interesting to note that with many axles the preload on the pinion bearings is such that, quite apart from the functioning of the gear and pinion teeth, seizure of the bearings does occur in a very few minutes when the lubricant is an untreated mineral oil. Once wear of the teeth has taken place to any extent, smooth and silent operation is no longer possible, although it is known that a progressive slow reduction in preload, with consequent gradual adjustment of bedding, does not cause a noisy axle to the same extent as a quick fall off in preload which fails to give the gear contacts time to accommodate themselves to the changed conditions.

Stability

It is essential that there should be the minimum change in the lubricant with the passage of time. This means :—

(*a*) that there should be no tendency for the additive to precipitate out;

(*b*) that the lubricant should not be subject to chemical changes, such as oxidation, which would result in viscosity increase and the formation of sludges and acids, all of which can cause failure of the ball or roller bearings or gear-teeth;

(*c*) that the loss in load-carrying capacity with use between the periods of oil drainage shall be insufficient to interfere with the proper functioning of gears and bearings, although with the knowledge that new gears and bearings require extra load-carrying capacity during the break-in period, some small loss may be permissible.

Non-corrosive

The properties of the lubricant must be such as to protect the gears and bearings from corrosion, particularly under conditions where water may have entered the axle casing either from condensation or leakage into the casing under such circumstances as wading through floods.

Compatibility

Since, even by draining the oil from an axle when it is hot it is impossible to ensure that the whole of the oil is drained, it is most essential that the lubricant should be compatible with other commercially available products. Most British axle manufacturers also attempt to guard to some extent against lack of compatibility by stressing that an axle should be drained completely rather than topped up, possibly with a different lubricant.

Low Foaming and Channelling Characteristics

The necessity for these properties is obvious.

American Specifications and Test Procedures

In America for many years prior to the second world war certain manufacturers had, on changing over to hypoid axles, commenced to specify the type of lubricant they approved for use in these axles. In many cases they went so far as to specify the chemical limits on sulphur, chlorine, and lead, as well as the usual limits of physical properties, usually with the object of restricting the approved oil to one commercially available product.

In 1942, however, a Federal Specification known as VV-L-761 was issued for so-called Universal Gear Lubricants. As will be seen from Table I, this specification broke away from the tight restrictive chemical specifications. It did, however, contain the following clause " the lubricant shall consist of a well-refined mineral oil and a load-carrying additive containing sulphur and chlorine with or without the admixture of other additive."

TABLE I

Federal Specification VV-L-761

(Later adopted by American Army Ordnance under the term 2-105A)

1. *Approval Tests on Additive*
   (*a*) Solubility.
   (*b*) Rate of shear.
   (*c*) High-torque test on full-scale axle.
2. *Approval Tests on Finished Lubricant*

Viscosity index	85 min
Channel test	Pass
Load-carrying capacity as determined by SAE machine :	
Before heating, at 1000 r.p.m.	325 lb/min
After heating, at 500 r.p.m.	400 lb/min
Shock test	Pass
Stability test :	
(*a*) Viscosity increase	25% max
(*b*) Insoluble material	0·5% max
(*c*) Evaporation loss	10·0% max
Corrosion test :	
(*a*) 1 hr at 212° F, copper-strip	Negative
(*b*) 1 hr at 300° F, copper-strip	Positive
Foaming test, ml	650 max

The feature of this specification is that the first three requirements concerned the additive only, which for test purposes was to be blended in U.S. Navy Oil No. 1080. The high-torque test specified was to be carried out on a Chevrolet axle, and consisted of a running-in procedure followed by 300,000 pinion revolutions at 185° F, 324 r.p.m., and a pinion torque of 1157 lb-ft, followed again by 25,000 pinion revolutions in succession under the same conditions but at temperatures of 210° F, 235° F, and 260° F. The lubricant was considered to pass if no scoring occurred.

The shock test was to be carried out on a Chevrolet passenger car by accelerating to 70 m.p.h., disengaging the clutch, and turning off the ignition. At 65 m.p.h. the clutch was then engaged and the car permitted to decelerate to 40 m.p.h., this cycle being repeated fifteen times, and the axle then inspected for damage to the surface of the gear-teeth.

The requirements of the copper-strip test for corrosion should be noted, since the demands of negative result at 212° F and positive at 300° F mean that the additive must become chemically active at some intermediate temperature. It should be noted also that this specification called for load-carrying-capacity figures on the SAE machine.

This Federal or civilian specification was later adopted by the American Army Ordnance as the specification for oil to be used by all their ground Forces, and was renamed 2-105A.

In March 1946 U.S. Army Specification 2-105B was introduced, this specification being the result of combined recommendations of the equipment manufacturers and the oil industry. The general requirements of the specification are set out in Table II. From this it will be seen that the physical properties divide the oil into three grades, *i.e.*, SAE. 75, 80, and 90. Only two small-scale laboratory tests are specified—a copper-strip test in which there must be no blackening at 250° C (as compared with negative at 212° F and positive at 300° F for the previous specification). This permits a reduction in chemical activity. The second test is a rust-

TABLE II

U.S. Army Specification 2-105B

(Later became MIL-L-2105)

(A) Physical and Laboratory Tests	Grade 75	Grade 80	Grade 90
Viscosity at 100° F, SUS	150–190	—	—
Viscosity at 210° F, SUS	—	55–65	80–90
Viscosity Index, min	85	85	85
Flash Point, °F, min	300	325	325
Channel Point °F, max	−50	−50	0
Copper Strip Activity	Pass	Pass	Pass
Rust Protection	Pass	Pass	Pass

(B) *Qualification Requirements on Full-scale Axle*
High-speed axle test
High-torque axle test
Moisture corrosion axle test

(C) *Additional requirements*
Storage solubility test
Foaming test

protection test in which a steel strip is rotated in the lubricant containing approximately 3 per cent water. The main core of the specification is, however, built up on three full-scale axle tests, with the additional requirements of storage solubility and foaming tests. It will be noted that laboratory bench-test machines are not used for indicating film strength and that this property is determined entirely by the full-scale tests on complete axles.

April 1950 brought about a change in the designation of this specification from 2-105B to MIL-L-2105 without other modification.

American Rigs and MIL-L-2105 Test Procedure

High-torque, Low-speed Test

(a) *Equipment.* A standard Chrysler ½-ton truck axle.

(b) *Running Conditions.* Ring gear speed throughout 62 r.p.m. Twenty minutes running-in followed by 30 hr operation at 32,311 inch lb ring-gear torque. Temperature of oil in axle permitted to run to 250° F, then reduced to 200° F by supplying cooling water to jacket surrounding axle casing. The water supply is then cut off until temperature reaches 250° F again and the cycle is repeated.

(c) *Test Rigs.* Two types of rig have been used, a " four square " or back-to-back rig using the test axle and a slave axle together with four right-angle-drive gear-boxes, the motive power being an electric motor coupled to one of these gear-boxes. A somewhat elaborate means is necessary for applying the torque while the system is in motion. Fig 1 illustrates a typical " back-to-back " rig.

A more satisfactory rig set-up is shown in Fig 2. In this rig large-capacity dynamatic dynamometers are coupled to each of the axle half-shafts, the capacity of each dynamometer being ample to deal with the maximum torque even at the low-speed condition of the test. A large slow-speed electric motor provides the motive power, and is coupled direct to

the propeller shaft. The two dynamometers are electronically controlled so that their speeds are identical, thus eliminating work by the differential unit.

High-speed, Low-torque Test

(a) *Equipment.* A standard Chevrolet passenger-vehicle axle.

This test can be carried out either on the road on a chassis dynamometer " provided that the roll torque throughout the entire speed range and the kinetic energy of the rolls at 70·2 m.p.h. are identical with the effective road conditions." Some companies prefer the road test and some the dynamometer, but it is understood the official preference is for the road test.

(b) *Conditions of the Test.* These are such that a new axle assembly is fitted for each test. The new components are then run-in for from 5 to 25 miles at a speed not above 25 m.p.h. The specified test conditions then are : in top gear accelerate to 40 m.p.h. Upon reaching 40 m.p.h. close the throttle and coast to 10 m.p.h. with the clutch engaged, repeat to a total of four times. Gradually accelerate to 60 m.p.h., open the throttle fully and accelerate to 80 m.p.h. Immediately close the throttle completely and coast to 60 m.p.h. with the clutch engaged. Repeat the drive and coast between 60 and 80 m.p.h. to a total of ten times.

If inspection shows no scoring of the ring gear and pinion teeth, a duplicate test is to be made using fresh lubricant and a new and unused third-member assembly. It is also specified that if scoring of the ring gear and pinion teeth occurs on any test and is attributed to abnormal conditions, that test shall be voided and the test re-run using fresh lubricant and a new and unused third-member assembly. A typical laboratory arrangement for carrying out the high-speed test is shown in Figs 3 and 4, from which it will be seen that the rear wheels of the car are arranged to drive heavy cast-iron rollers of the specified inertia, and that these rollers are in turn coupled by belt drive to a dynamatic dynamometer.

Although not in accordance with the 2-105B specification, the above test is sometimes made more severe by increasing the number of 60 to 80 m.p.h. cycles from ten to a total of twenty-five. Certain oils which are satisfactory on the normal procedure are known to fail when the number of cycles is increased.

Moisture Corrosion Test

This is carried out on a Chevrolet passenger-car axle built up with all new parts with the exception of the housing. Special attention is paid to the cleaning of the parts before test by washing in caustic soda solution and then rinsing with methanol. Into the axle is then poured distilled water equivalent to 2 per cent of the total fill, and then the test lubricant is added to the normal level. The propeller shaft is then rotated at 2400 r.p.m. under no-load conditions for 4 hr with the oil temperature maintained constant at 180° F. At the end of this period the drive is stopped and without draining the axle is stood for ten days in a position corresponding to its position in a car. After ten days the unit is disassembled and inspected. The parts are then rated on a numerical scale of 5 for clean with no rusting down to 1 for heavy rusting. In this connexion it should

be noted that oils to the former VV-L-761 specification, before this specification required the use of a rust buffer, showed the most rusting, followed by base oil, and finally 2-105B products, which should be free from rust.

An Equivalent British Test Procedure

Since the 2-105B specification was accepted by the American Army Ordnance and was in addition the requirement of the British Ministry of Supply for axle lubricants, and since, moreover, 2-105B type lubricants were giving satisfaction as hypoid lubricants in the U.K., it was inevitable that, when deciding on a British test procedure it should be based on 2-105B. Consideration was first given to the possibility of utilizing American components, but this was rejected for the following reasons : (*a*) the difficulty and cost of obtaining replacement parts, particularly in view of the dollar situation and the necessity for obtaining Board of Trade and Treasury permission, and (*b*) the fact that it was desirable, apart from the above considerations, to use British components so that the work carried out could relate directly to British axles.

At the same time it was equally obvious that results obtained on the British tests should correlate with the American procedure, and accordingly arrangements were made to obtain from America three reference oils, a pass oil, a borderline-failure oil, and a failure oil for both the high-torque and the high-speed tests.

The type of axle in largest production in the motor industry of the U.K. appeared to be that manufactured by the Standard Motor Company for their Vanguard cars, and this firm agreed to co-operate in the supply of axles, and replacement gears. Their Engineering and Service Departments in particular have been most helpful. The components used are taken straight from the Standard Company's production, since the only difference from the assembly as fitted to the cars is that the gears and pinions are supplied before Parco-lubrized, *i.e.*, immediately after the final lapping process. Having taken a decision to use the Vanguard axle, there seemed no logical reason why this same axle should not be used for high-torque, high-speed, and moisture corrosion tests, and investigation proceeded along these lines.

High-torque, Low-speed Tests

The Rig. In view of the difficulty in obtaining within a reasonable time low-speed dynamometers of the absorption capacity required, it was decided that a modified version of the American test rig would have to be adopted. Accordingly, it was decided to couple to each half-shaft a gear unit giving approximately a 10 : 1 step-up, and then to couple the output shaft of each of these gear units to either end of a Heenan & Froude Mark I dynamatic dynamometer of relatively low absorption capacity. The general arrangement of these gear units and the dynamometer can be seen from Figs 5, 6, and 7. Flexible couplings are interposed both between the axle and the gear units and the gear units and the dynamometer. It was at first thought possible that these flexible couplings might introduce torsional problems into the test results, but as will be seen later, this has proved unfounded. The source of motive power for the rig is a 5·6-litre

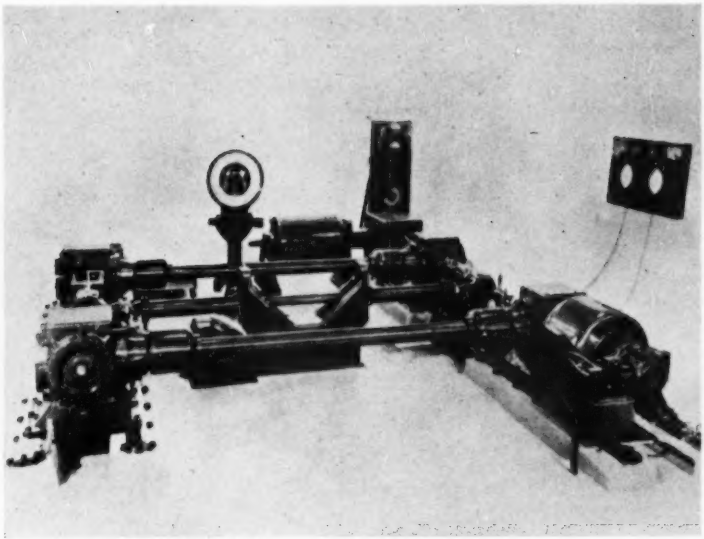


FIG 1

"FOUR-SQUARE" OR "BACK TO BACK" RIG FOR HIGH-TORQUE, LOW-SPEED TESTS

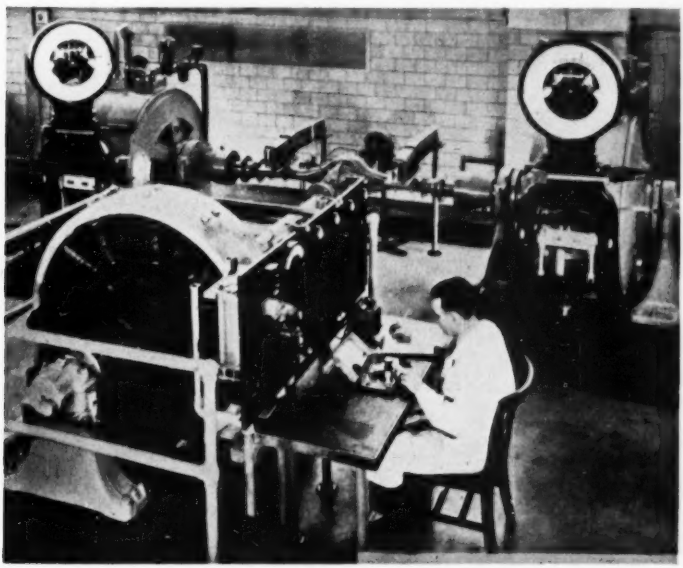


FIG 2

ARRANGEMENT OF DRIVING MOTOR AND LARGE-CAPACITY DYNAMOMETERS FOR HIGH-TORQUE, LOW-SPEED AXLE TEST

[*To face p.* 754.

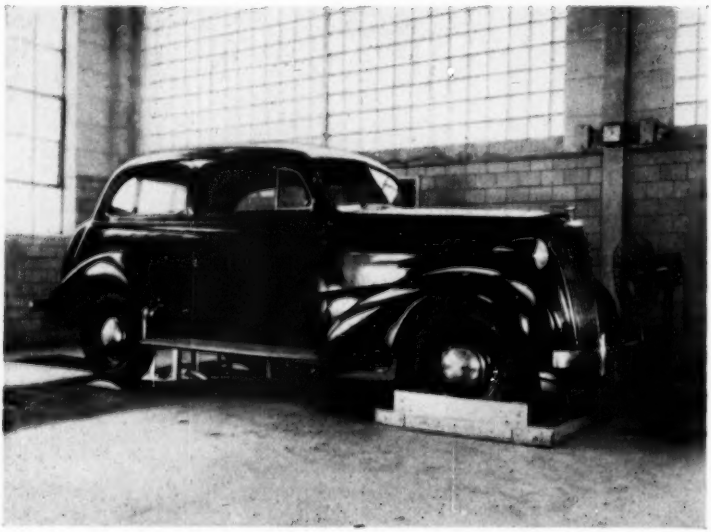


FIG 3

CAR MOUNTED ON CHASSIS DYNAMOMETER FOR HIGH-SPEED, LOW-TORQUE TEST

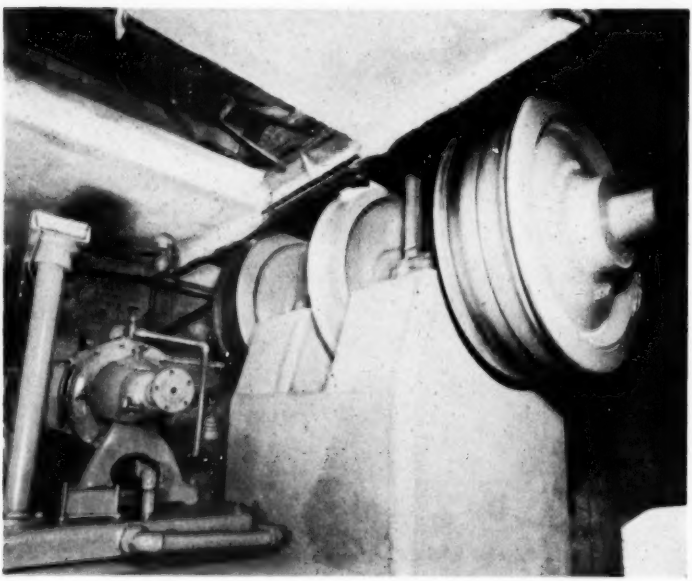


FIG 4

ARRANGEMENT OF ROLLERS AND DYNAMOMETER FOR HIGH-SPEED, LOW-TORQUE TEST

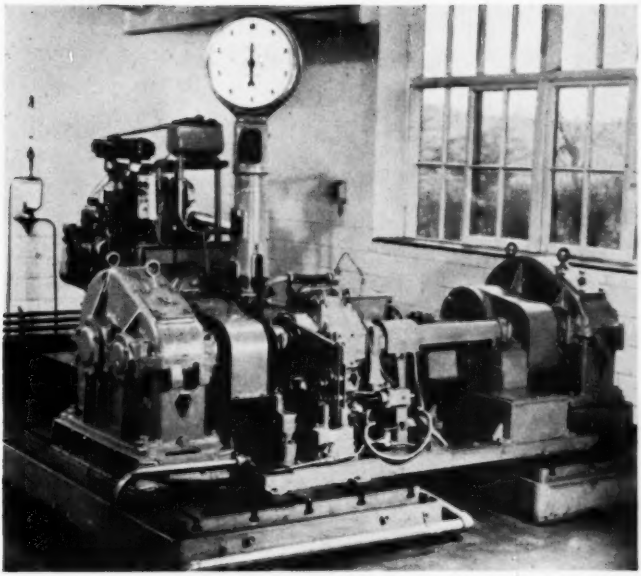


FIG 5

GENERAL VIEW OF HIGH-TORQUE RIG SHOWING ARRANGEMENT OF DYNAMOMETER AND STEP-UP GEARS

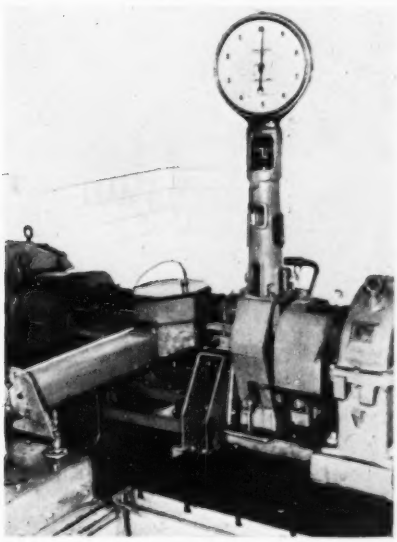


FIG 6

MOUNTING OF AXLE AND GEAR UNITS FOR HIGH-TORQUE RIG

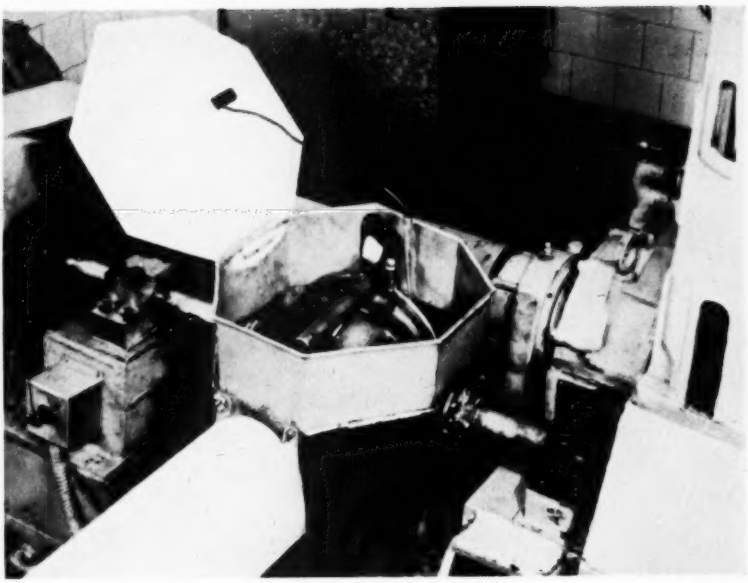
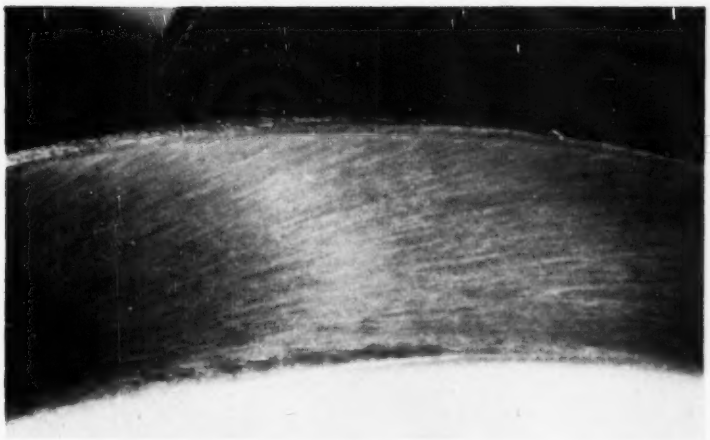
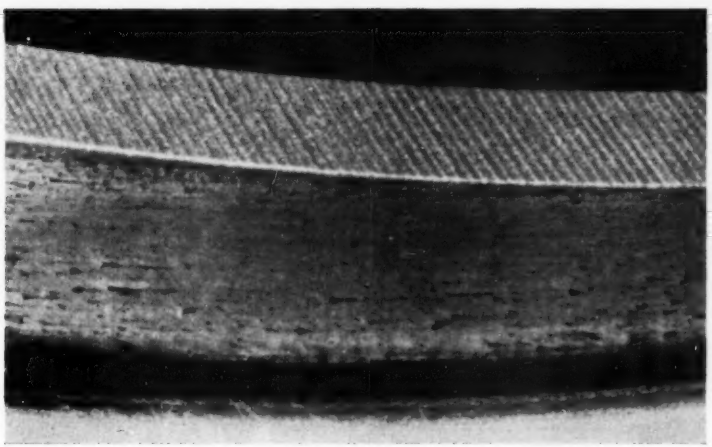


FIG 7

ARRANGEMENT OF COOLING SYSTEM HIGH-TORQUE RIG



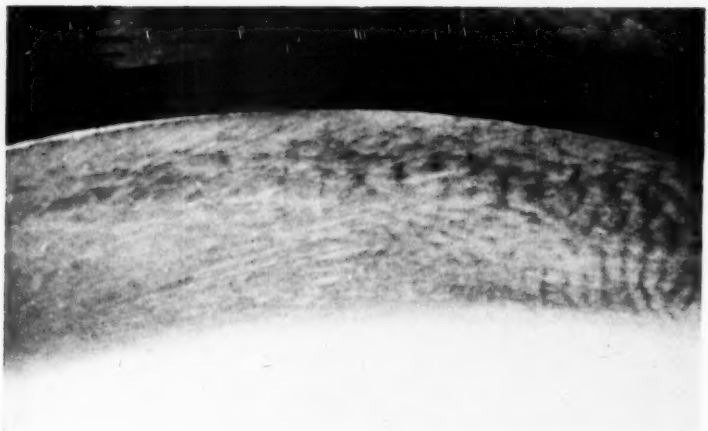
PINION



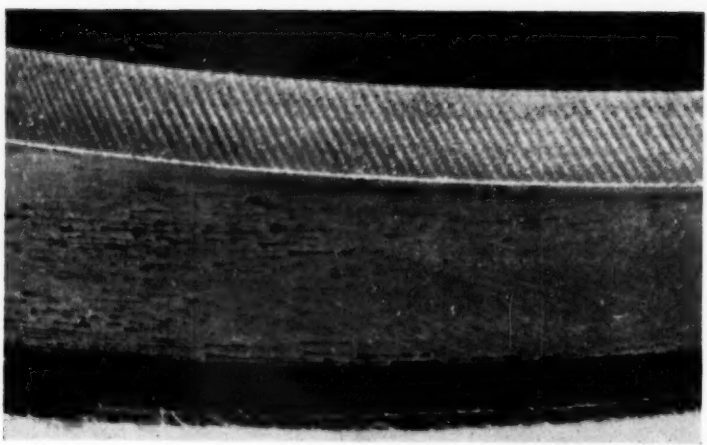
GEAR

FIG 8

PINION AND GEAR AFTER BRITISH HIGH-TORQUE TEST ON REFERENCE PASS OIL



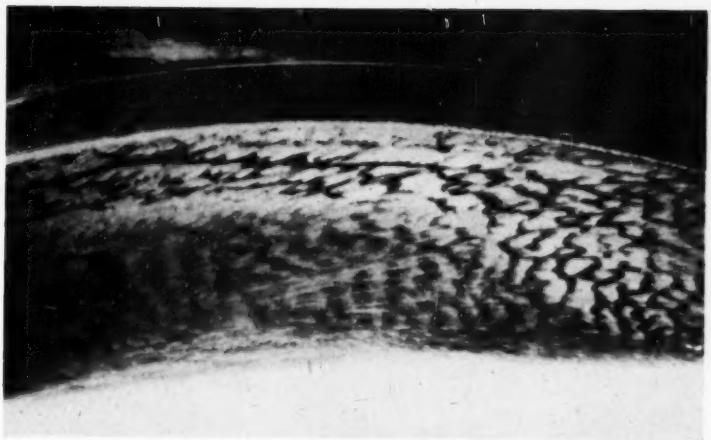
PINION



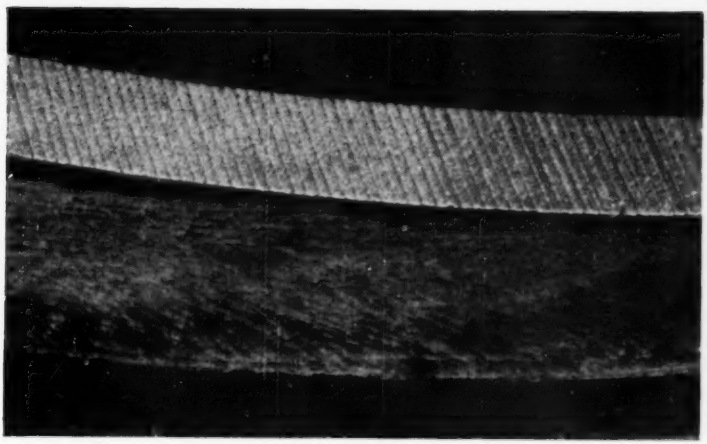
GEAR

FIG 9

PINION AND GEAR AFTER BRITISH HIGH-TORQUE TEST ON REFERENCE BORDERLINE-FAILURE OIL



PINION



GEAR

FIG 10

PINION AND GEAR AFTER BRITISH HIGH-TORQUE TEST ON REFERENCE FAILURE OIL

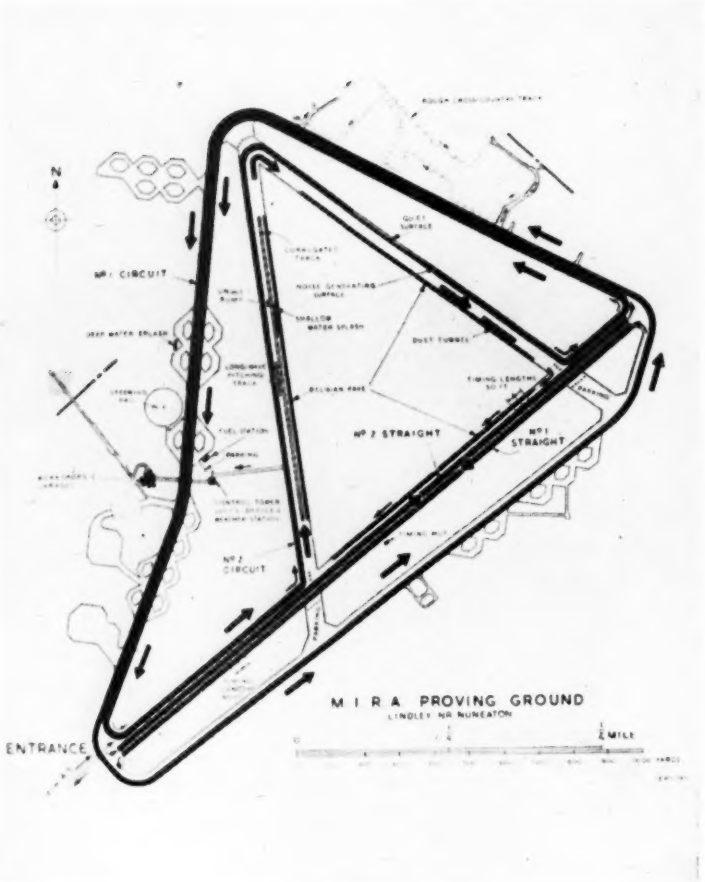


Fig 12

LAYOUT OF MIRA PROVING GROUND TO BE USED FOR HIGH-SPEED AXLE TESTS

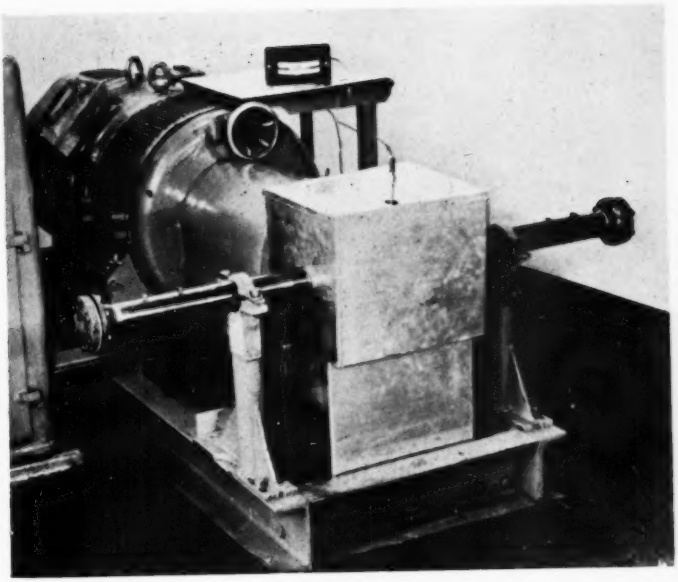
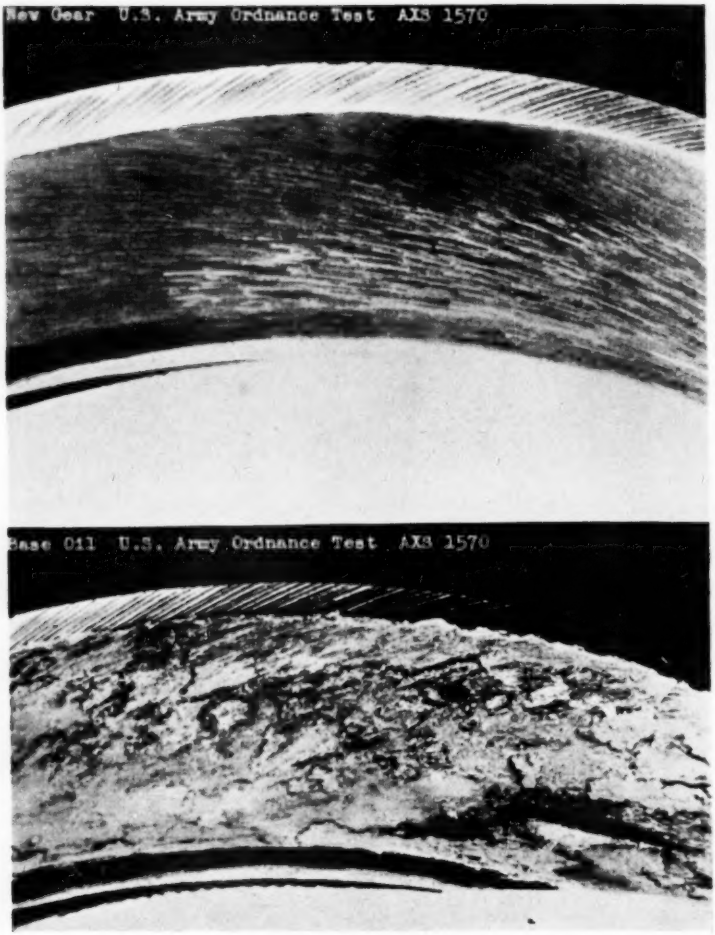


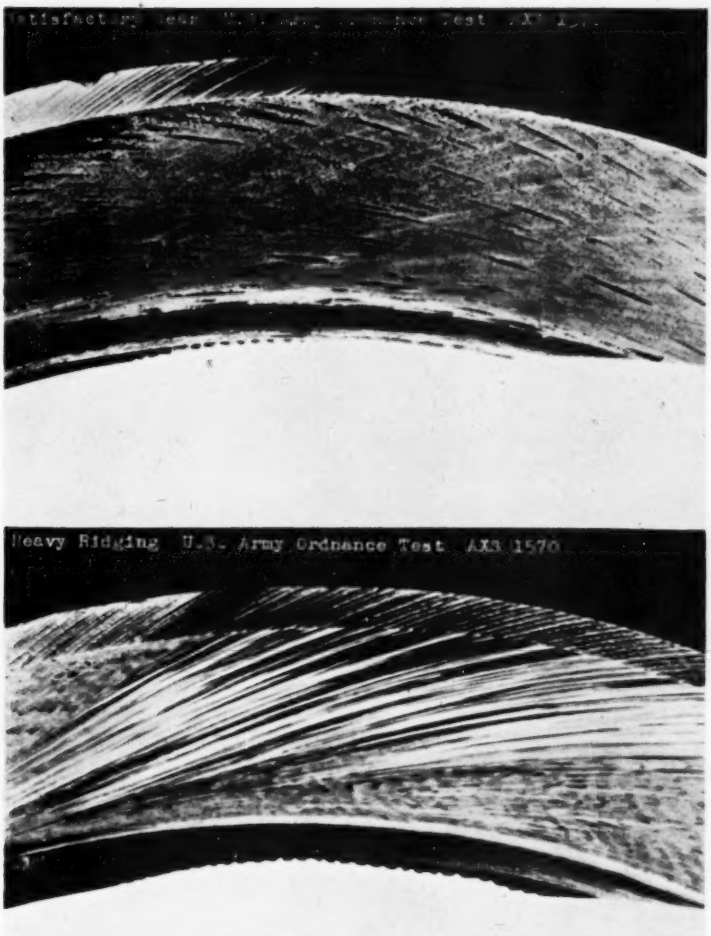
FIG 13

ARRANGEMENT OF MOISTURE CORROSION TEST RIG



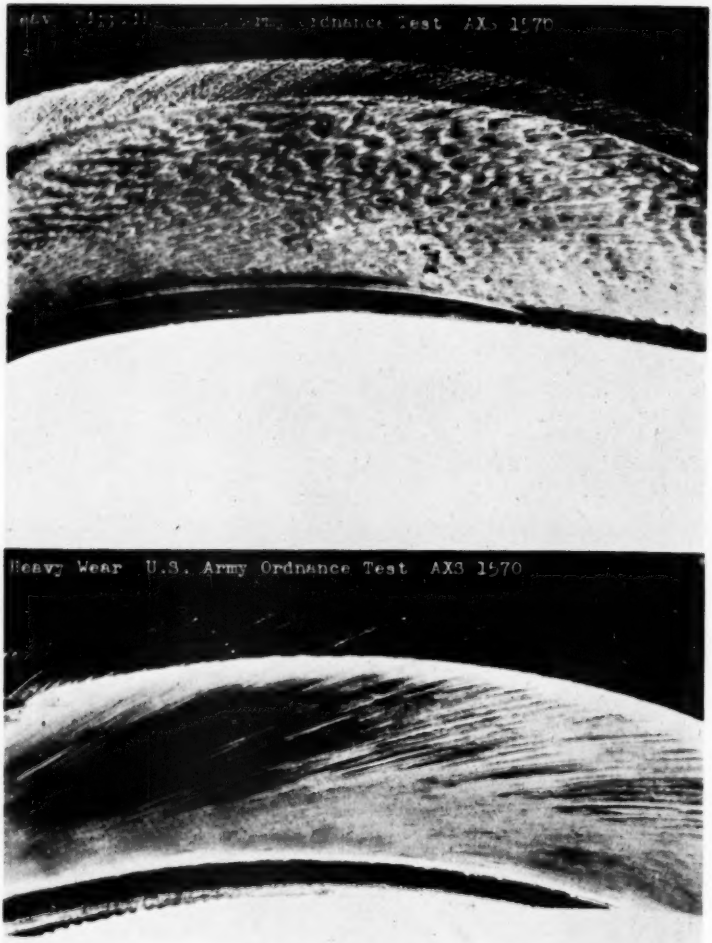
FIGS 14 (*a*) and 14 (*b*)

SHOWING CONDITION OF NEW PINION AND A PINION RUN ON THE HIGH-TORQUE TEST USING A BASE OIL



FIGS 15 (*a*) and 15 (*b*)

SHOWING CONDITION OF HIGH-TORQUE TEST PINIONS AFTER RUNNING ON A SATISFACTORY OIL AND AN OIL PRODUCING HEAVY RIDGING RESPECTIVELY



FIGS 16 (*a*) and 16 (*b*)

SHOWING CONDITION OF HIGH-TORQUE TEST PINIONS AFTER RUNNING ON OILS PRODUCING HEAVY RIPPLING AND HEAVY WEAR RESPECTIVELY

Gardner 4-cyl C.I. engine, and this is coupled directly to a Morris armoured-car four-speed gear-box. By a suitable selection of gear-ratio and engine speeds a wide range of speeds is available at the engine half-shafts, but for normal test purposes the engine is operated at 600 r.p.m., which, with third gear engaged in the gear-box, gives the required speed of 62 r.p.m. at the half-shafts. Gear-box and axle are connected by a commercial-vehicle propeller shaft fitted with Hardy Spicer needle roller universal joints. The dynamometer is offset slightly from the centre line in order to clear the axle housing, and modifications are also necessary to the pedestal supporting the dynamometer scale to prevent it fouling the axle tube. This is accomplished by fabricating a simple suitably shaped support and a corresponding link, which are interposed between the pedestal and the base of the dynamometer.

The axle casing is surrounded by a fabricated cooling pan fitted with a hinged cover and coated with a bitumastic-asbestos compound to prevent heat losses by air currents.

Instrumentation used includes an Ether maximum and minimum regulating and indicating pyrometer, which is connected to a thermo-couple situated in the axle near to the lower end of the ring gear. This regulator automatically controls the axle-oil temperature between the maximum and minimum limits of 250° and 200° F respectively. This is accomplished by operating a Teddington magnetic valve which switches on and off cooling water to a sprayer situated in the cooling pan. The cooling water escapes from the pan by means of an overflow pipe situated about half-way up the casing, and also by means of a drain at the lowest point of the cooling pan, this latter being fitted with a valve so adjusted that when the cooling water switches off the cooling pan empties in 1 minute. Also connected to the axle thermocouple is a recorder arranged to give a permanent graphical record of the temperature cycle, and a revolution counter is mounted so as to record the number of revolutions of the half-shafts.

Assembly of Axle. (*a*) The axle housing, metal cover plate, differential bearings, and housing are first cleaned.

(*b*) A new pinion is then assembled with a preload torque of 10 ± 1 inch lb. New pinion-shaft bearings are used for each test.

(*c*) The oil seal is then fitted, and the breakage torque of the pinion plus oil seal is determined.

(*d*) A new ring gear is next assembled with a backlash of 5–7 thou as measured by means of a dial gauge clamped to the axle housing on the extreme tip of the ring gear. Six backlash readings on different teeth are taken, and the mean of these readings is recorded. With the backlash set between 5 and 7 thou the bedding of the teeth should be satisfactory, since both pinion and ring gears are specially paired and lapped by the manufacturers, the pinion being marked on its end face to indicate what shim should be necessary (if any) in order to ensure correct bedding on assembly. The bedding is further checked before test by painting ten of the teeth with Prussian blue and rotating the pinion until a good impression of contact is obtained. Fitting bolts, nuts, and tab washers are used in place of the standard rivets for attaching the ring gear to the differential housing in order to facilitate assembly.

(*e*) After satisfactory bedding has been ensured, the gear-teeth are thoroughly cleaned and the ring gear and half-shafts assembled; the breakage torque of the ring gear, plus pinion plus oil seals being determined with and without half-shafts.

(*f*) All joints are then sealed by means of a sealing compound to ensure that the axle is water-tight.

(*h*) The axle is then filled with 2 pints of the test oil.

Test Conditions. (*a*) The engine is first warmed up with the gear-box in neutral in order to ensure easy starting when the engine is coupled to the axle.

(*b*) The gear-box is put into third gear and with no load on the brake the ring-gear speed is taken up to 62 r.p.m., and initial load of 1555 inch lb is then applied to the ring gear, and this condition is held for 30 minutes. There is no flow of cooling water during this period, and the axle-oil temperature does not normally exceed 60° C.

(*c*) The ring-gear-tooth contact surfaces are then inspected at the end of this running-in period through the inspection hole. If the contact is satisfactory the test is continued as follows:

(*d*) With the gear-box in third gear and no load on the brake the ring-gear speed is again taken up to 62 r.p.m., and then load is incrementally applied to the brake until a torque of 10,770 inch lb is applied to the ring gear, at which torque the test is continued for a duration of 30 hr.

(*e*) The axle temperature is allowed to run to 250° F, at which temperature the automatic controller cuts in, allowing a flow of cooling water on to the housing. This fills the cooling pan to the level of the overflow outlet. The automatic control is so adjusted that the flow of cooling water is cut off at such a point that the axle-oil temperature does not fall below 200° F. During the 30 hr test at full load the oil temperature is permitted to cycle between this range of 200° and 250° F.

(*f*) The duration of the temperature cycle cannot be controlled, since it is dependent upon the tightness of the axle bearings and the pinion-shaft oil seal and also upon the properties of the test lubricant. The characteristic of this cycle is recorded automatically by the temperature recorder. The duration of the cycle is longer than that for the corresponding 2-105B American test, since the ratio of surface area to transmitted torque is considerably greater in the case of the British axle.

(*g*) The run should preferably be continuous, and not more than four stops are allowed during which the oil may cool to room temperature.

(*h*) At the end of the test the total ring-gear revolutions are recorded and the axle is immediately disconnected from the step-up gears and the gear-box drive. The oil is then drained from the axle and a 1-pint sample retained for chemical analysis. The total breakage torque is then measured while the axle is hot and the corresponding cold torques to those before test also taken. Measurements are also taken of the backlash after test.

(*i*) The axle is then completely stripped for examination, and after inspection the components are immediately dipped in a preservative oil.

It was originally intended to make the test torque the same proportion of the maximum service torque which can be applied to the ring gear, as in the 2-105B procedure on the Chrysler truck axle, *i.e.*, 39·2 per cent, but experience on the reference oils indicated that this torque was in-

sufficient to give borderline failure on the borderline oil. Consequently, the torque on the test was increased to 59 per cent of the maximum torque which could be applied by the Vanguard engine in service, and this condition was found to bring about the desired degree of severity.

Inspection. (*a*) The axle shafts are examined for condensation rust and other deposits.

(*b*) The axle housing is examined for discoloration deposits or water.

(*c*) The carrier housing is examined for discoloration and deposits.

(*d*) The pinion-tooth surfaces on the drive side are examined for evidence of the following :—

(1) burnishing
(2) scratches
(3) wear
(4) surface fatigue
(5) scoring
(6) discoloration
(7) corrosion

} see details of each of these types of failure later in the paper.

(*e*) The ring-gear-tooth contact surfaces are examined for any of the conditions as listed in (*d*) above.

(*f*) The ring-gear and pinion assemblies are examined for evidence of deposits.

(*g*) The bearings are examined for evidence of :—

(1) discoloration,
(2) corrosion,
(3) deposits,
(4) wear.

The used oil is examined in comparison with new oil for evidence of water and other foreign material, sludge, discoloration, etc.

Results of Tests. Figs 8 to 10 inclusive show photographs of gears run with reference 2-105B high-torque procedure—pass, borderline, and failure oils from which it will be seen that the British results do correlate very well with American experience. Further tests on other oils have confirmed this correlation, and Fig 11 compares the ring gear and pinion from a British test on an oil which fails to meet the specified performance standard with those obtained on the corresponding American test on the same oil. It should be noted that in the high-torque test procedure it is the pinion which first shows signs of surface distress, while in the case of the high-speed test it is usually the ring gear.

High-speed, Low-torque Tests

Rather than attempt to simulate the correct conditions on a rig it was decided to carry out these tests on the road, the MIRA Proving Ground at Lindley near Nuneaton being selected for this purpose. Correlation tests are now in progress using a Vanguard car on three American " high-speed " reference oils to the following test procedure :—

(*a*) The car is a Standard Vanguard with all-up weight of 27 cwt (ballast being added as necessary) and 26 p.s.i. pressures are used for both front and rear tyres.

(*b*) The axle shafts and housing are cleaned and dried and assembled with new ring gear, pinion shaft, and bearings, the axle is then filled with 2 pints of the test oil.

(*c*) Following the installation of the test axle in the car, three laps of the perimeter track are completed at a speed building up to 25 m.p.h. in top gear.

(*d*) During the fourth lap the car is accelerated to 40 m.p.h. in top gear, and upon reaching 40 m.p.h. the throttle is closed and the vehicle coasted to 10 m.p.h. with the throttle closed. This being repeated to a total of four times.

(*e*) The car is then accelerated on full throttle to 70 m.p.h.; the throttle closed completely and the car allowed to coast to 50 m.p.h. with the clutch engaged. Proceeding round the perimeter track, this process is repeated to a total of ten times, for each lap it being possible to carry out five cycles.

(*f*) The axle is then inspected for scoring of the ring gear and pinion teeth, and if there is no scoring a duplicate test is carried out using fresh lubricant and a new axle assembly.

These calibration tests are still in progress to determine whether the schedule given above is the most satisfactory one for correlation. Tests are also in hand to investigate the influence of extending the number of speed cycles.

Fig 11 illustrates the MIRA proving ground and shows how the five cycles per lap of the perimeter track are obtained.

Moisture Corrosion Tests

A Standard Vanguard rear axle is assembled as for the high-torque tests, with the exception that the half-shafts are omitted and their holes in the axle casing are plugged up at the gear end. New pinion shaft, ring gear, and bearings are used, and all components are thoroughly cleaned by successive washes in trichlorethylene, sodium hydroxide, and water, and are finally dried by rinsing in methanol followed by air blast. The assembled axle is then installed on the rig shown in Fig 13. Two pints of the test oil already blended with 2 per cent of distilled water are then added, and the pinion is rotated for a period of 4 hr at a speed of 2000 ± 25 r.p.m. by a small electric motor, during which time the lubricant is maintained at a temperature of $82° \pm 1°$ C by use of an automatic control arranged to govern the delivery from a cooling fan. Heaters are installed to enable the test temperature to be obtained in about 25 minutes, and these are switched off once the desired temperature is obtained. At the end of the 4-hr period the motor is stopped and the axle test unit placed in a storage rack in a horizontal position for ten days at room temperature without draining the lubricant. At the end of the ten-day storage period the lubricant is drained and the axle stripped for inspection.

The following items are then rated on a merit system from 1 to 5 according to their freedom from rusting ring gear, pinion, pinion bearings, differential bearings, differential gears. An oil of satisfactory 2-105B quality should give a total merit rating of 24 or 25 out of 25.

Possible Types of Failure of Hypoid Gears

Given satisfactory lubrication, correct stressing and manufacture, there is no reason why the life of the hypoid rear-axle gears and bearings should not at least equal that of the remainder of the car. There are, however, a number of ways in which the gear surfaces may fail by surface distress due to unsatisfactory lubrication, insufficient rigidity of pinion shaft and casing, faulty tooth profile or faulty manufacture generally, and the terminology universally used to describe the condition of the gear surfaces is as follows :

Burnishing

An alteration in the original manufactured surface to a dull or brightly polished condition with or without the elimination of all tool, grinding, or lapping marks but without evidence of wear, surface fatigue, or other surface defect.

Hypoid gears which have been correctly designed, manufactured, and lubricated should exhibit a burnished appearance.

Scratching

An alteration in the tooth surface in the form of irregular grooves running at random across the tooth surface in the direction of sliding of the surfaces such as is caused by coarse abrasive particles, or other accidental injury to a tooth surface.

If the abrasive is fine, on the other hand, a highly polished surface may result, and unless the oil is drained and the axle flushed will be followed by excessive wear both of gears and bearings.

A common cause of " scratching " on new axles is core sand working out from the casting, and the possibility of this should be eliminated by painting the whole of the inside of the axle casing and differential carrier with one of the special paints which can be obtained for this purpose. Care must also be taken to prevent the entry of dirt particles when draining and refilling the axle.

Surface Fatigue by Rippling

An alteration of the tooth surface to give an appearance of more or less regular pattern resembling ripples on water, and presumably brought about by displacement of metal in front of the point of contact, possibly as a result of surface temperatures high enough to soften the surface layer of the teeth. Such rippling is much more pronounced on the pinion than the ring gear, and usually occurs under conditions of low-speed, high-torque. Rippling results in noisy operation, and if service is continued gives rise to ridging and eventually flaking. A typical rippling failure is shown in Fig 16(*a*).

Surface Fatigue by Ridging

An alteration to the tooth surface to give a series of parallel raised and polished ridges running diagonally either partially or completely across the tooth surfaces. Ridged surfaces again result in noisy operation and

finally breaking away of the surface. A typical ridging failure is shown in Fig 15(*b*).

Surface Fatigue by Pitting

Small irregular cavities in the tooth surface brought about by the breaking out of areas of surface metal consequent upon local overloading through incorrect tooth profile, coarse surface finish, or material imperfections in the gears.

Pitting failures are most common on spur-type gears, less common on spiral bevel, and seldom encountered on hypoid gears. The relative absence of failures on this latter type of gears being possibly connected with the difference in sliding action of the teeth.

Surface Fatigue by Spalling

The breaking out of flakes of irregular area of the tooth surface, a condition more extensive than pitting.

Surface Failure by Scoring

The displacement of metal from one tooth to another of mating teeth resulting in the development of a pattern of scratches running diagonally across the tooth surface of hypoid gears. The effect is cumulative, and experience shows it most likely to occur under high-speed conditions.

Surface Failure by Scuffing

Surface welding of the teeth of the pinion and gear due to the inability of the oil film to carry the imposed load and so prevent metal-to-metal contact. In hypoid gears mild scuffing may be obliterated by further running, and failure then takes the form of wear.

Surface Failure by Wear

Shown by the presence of a shoulder ridge at the bottom of the contact area near the roots of the pinion or gear-teeth or at the toe or heel end of the contact area. A typical failure by heavy wear is shown in Fig 16(*b*).

Service Experience on Hypoid Lubricants

The success of the 2-105B specification for hypoid oils may be judged from the fact that an extremely high percentage of the hypoid gear lubricants sold in the world to-day are of a type fulfilling this specification and by the fact that oils to this specification are universally adopted both by the British and American Armed Forces as well as the Armed Forces of most of the other Atlantic Treaty Powers. In general, such lubricants have been giving very satisfactory results, and where troubles have been experienced it has usually been tied down either to incorrect design or manufacture of a new type of axle, or alternatively to the replacement of the lubricant with a straight oil after draining.

2-105B lubricants have not, however, found universal favour for " factory fill " in America, since in many instances it has been thought desirable to have increased additive activity to tide the gears over the period before their surfaces have become conditioned. For this purpose lead-soap

active sulphur materials are used by some manufacturers for factory passenger car fill, with the warning that such lubricants must be drained after mileages which are variously specified from 300 upwards to prevent excessive wear of the gears and bearings, and for the refill 2-105B lubricants are specified. In the U.K. 2-105B type lubricants have in most cases proved satisfactory for factory fill as well as for general-service use. Three factors would appear to have contributed to this.

(*a*) The larger ring gear in proportion to the power transmitted adopted by British manufacturers.

(*b*) The belief by British manufacturers that any complicated lubricant change procedure would be mishandled by the British garage trade, which is not as yet organized in the same way as in America to deal with such procedures.

(*c*) Adoption of the process of Parco-lubrizing of either or both the pinion and ring gear, so considerably facilitating running-in and the initial conditioning of the gear-teeth.

As regards loss in load-carrying capacity of a 2-105B oil with use in an axle, extensive tests have shown that at any rate up to a mileage of 10,000 loss in load-carrying capacity represents only a small fraction of the difference in load-carrying capacity between a straight and a new 2-105B type oil and has no influence on the continued satisfactory performance of the gear. It is suggested, therefore, that a reasonable change period for rear-axle oils is 10,000 miles.

Correlation with Small-scale Laboratory Machines

In America particularly considerable efforts were made over a period of years to find a small-scale laboratory test procedure which would satisfactorily rate oils in the order of their service performance in hypoid gears, but it is now generally recognized that these tests fail to correlate with service experience and that the only tests of value are full-scale ones carried out on hypoid axles themselves. To illustrate this a table published in a paper by W. B. Bassett is shown in Table III, and clearly indicates that it would be impossible from this data to suggest the most satisfactory of the lubricants considered.

Table III

Results of Film-strength Machine Tests

Lubricant	Almen, lb	Falex, lb	Timken, lb	SAE, lb at 1000 r.p.m.
Lead soap–active sulphur oil A	30+	4500+	25	550+
Lead soap–sulphur chlorine oil B	16±	2500±	68+	120±
2-105A Hypoid oil C	30+	4500	59	350
2-105B Hypoid oil D	30+	4500	43	200
Base oil	6	500	7	0

In the U.K. the Shell Four-ball machine has been used for extensive experimentation work on lubricating oils, and the results obtained on three

reference high-torque procedure and three reference high-speed-procedure oils indicated that of the three methods of assessing test results on the machine, *i.e.*, wear, load capacity, and 2½-second seizure delay, the load-capacity assessment rated the three oils in the same order as the high-speed test, but all three failed to rate oils in the same order as the high-torque test.

It is interesting to note the results given by the 3¼-inch IAE spur-gear machine running at 4000 r.p.m. on a number of oils which have been tested on the full-scale high-torque procedure, these are shown in Table IV. It will be noted that there is no correlation between the two sets of test results.

TABLE IV

Comparison Between IAE Machine and High-torque Test Results

Oil	High-torque procedure result	Comparative IAE load for scuffing
2-105B Hypoid oil A . .	Pass	100
E.P. gear oil B . . .	Fail	110
E.P. gear oil C . . .	Pass	80
E.P. gear oil D . . .	Border Fail	75
E.P. gear oil E	Border Fail	75
Base oil	Fail	37·5

CONCLUSIONS

Already there has been a big swing over to hypoid axles in the U.K., and there is no doubt that the next few years will see the virtual elimination of the spiral bevel axle from new British passengers cars, and probably the further adoption of the hypoid axle for commercial vehicles as well. Bearing in mind also the military requirements of the two countries, it is therefore extremely desirable that a British specification should be drawn up in the near future which will correlate with the American 2-105B or MIL-L-2105 specification for hypoid oils, and which will at the same time use British test components. The high-torque test described correlates well with the American procedure, and had already been accepted by the American Army Ordnance Reviewing Committee as an alternative to their own specification. Further work is on hand, as described, on high-speed and moisture corrosion tests using the same axle, and the author believes that in the near future they too will be acceptable to the American committee.

ACKNOWLEDGMENTS

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THE TESTING AND SELECTION OF GEAR LUBRICANTS

By H. J. WATSON *

THE lubricant is an essential component of a gear drive, and its selection must be given as much consideration as the choice of materials for a gear pair. It has two main functions, to form a separating medium between the " contacting " surfaces and to transfer heat from the tooth surfaces to the surrounding atmosphere. Of these the first is the more important, since in practice it means that the separating film is required to sustain without rupture the full load carried by the teeth, one of the most exacting of all lubrication requirements.

For a proper appreciation of the action of a gear lubricant some acquaintance with the results of defective lubrication is desirable since it is advantageous to diagnose, from a careful visual examination of a pair of gears giving trouble, whether or not the condition may be attributed to faulty lubrication and can accordingly in many cases be cured.

Tooth-surface defects which may be produced when gears run together may broadly be defined as " pitting " and " scuffing." Pitting is essentially a surface-fatigue condition, and is consequently a gear-material phenomenon virtually independent of lubrication, but because it is occasionally associated with some of the numerous forms of scuffing it is worthy of brief consideration. Causes of pitting on gear-teeth are controversial. Its occurrence is usually associated with high unit pressure, but unless it is progressive it is rarely detrimental to the life of a gear. The normal sequence of events is the formation of one or more pitted areas comparatively early in the life of a pair of gears which gradually increase in size to a maximum after which further pitting ceases. It is generally accepted that the removal of metal by this means results in a more evenly distributed load across the tooth flanks, thereby reducing the stress below the fatigue limit, and most rear-axle worm gears are examples of arrested pitting of this type.

The tooth-surface conditions which are conducive to pitting are also favourable for scuffing, although fortunately scuffing is much less prevalent. The latter is a lubrication failure in so far as the film of oil which should be interposed between the flanks of gear-teeth ceases to perform its function of preventing metal-to-metal contact. Irregularities of surface or tooth form, for instance, may be such that pressures in excess of the capacity of the oil result in breakdown of the film to a greater or lesser degree. Such conditions may occur simultaneously with pitting, and an example of this is illustrated in Fig 1.

At one end of the scuffing range lubricant breakdown results in a rate of wear greater than normal, but the tooth surfaces retain a smooth polished appearance, and if the conditions continue the tooth shape is retained

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over quite a long period of running. Metal appears to be removed in microscopic particles which eventually fall as sludge to the bottom of the oil sump.

In a more intensive form metal is removed as extremely thin irregular flakes which float in the oil, imparting to it a metallic sheen, but unlike the milder smooth abrasive wear, this type of scuffing results in a matt tooth surface which when closely examined is observed to be covered with very small ridges and hollows.

At the other end of the scale definite welding together of the tooth flanks at local spots occurs, producing ridging, scoring, or galling, often associated with high surface temperatures, and Fig 2 illustrates a gear which has suffered severely.

In practice there are two usually accepted means of mitigating the nuisance of scuffing or, if it has already taken place, of preventing its continuation, provided the tooth shape is reasonably accurate. The first is to employ a lubricant of higher viscosity with perhaps better lubricating properties but otherwise without an artificial load-carrying improver, the second is to use oil containing an extreme-pressure additive. These measures are only successful if, after making due allowance for the lubricant, the tooth-loading conditions are within the capacity of the gears.

A small increase in viscosity, however, can have quite surprising results in the elimination of some forms of scuffing, so also can the use of an oil with better lubricating properties without an increase in viscosity.

In some cases an extreme-pressure oil is essential, particularly where relative sliding is high, as with hypoid gears.

If, however, the tooth shape is such that load concentration is beyond the capacity of any lubricant to support it, scuffing can be prevented only by modifying the tooth shape. For example, a high concentration of load at the tips of a pinion tooth and the root of the wheel may be sufficient to break through the oil film.

With turbine gears, and particularly in marine applications, the crests of undulations are notoriously prone to scuffing trouble.

Scuffing may also be produced by the sudden application of a heavy load, even when gears have been thoroughly run-in, and doubtless there are other direct causes, but in every case the unit pressure on the contacting surfaces has exceeded the resistance of the lubricant present.

Before a gear lubricant can be selected for any particular application some knowledge of its properties for the required purpose must be known. It is obviously impracticable to determine the limiting capacity of every possible gear lubricant in an actual gear unit because of the time needed and the cost of test specimens. Numerous machines have been devised to test oils using comparatively cheap and simple test pieces but, unfortunately, the results of tests carried out on any given series of oils by these various testing machines do not always classify them in the same order. A possible explanation of the discrepancies may lie in their not testing the oils for similar mechanical requirements.

In gearing the tooth action results in a combination of rolling and sliding between the engaging flanks. Maximum sliding velocity occurs at the tip of a tooth and pure rolling on the pitch cylinders. With the exception of spiral gears, all practical types of toothed gearing make line contact

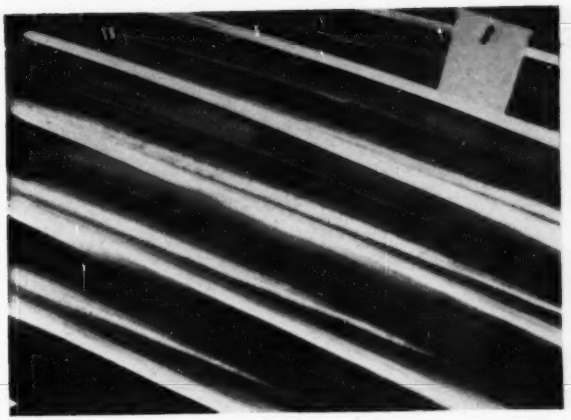

FIG 1

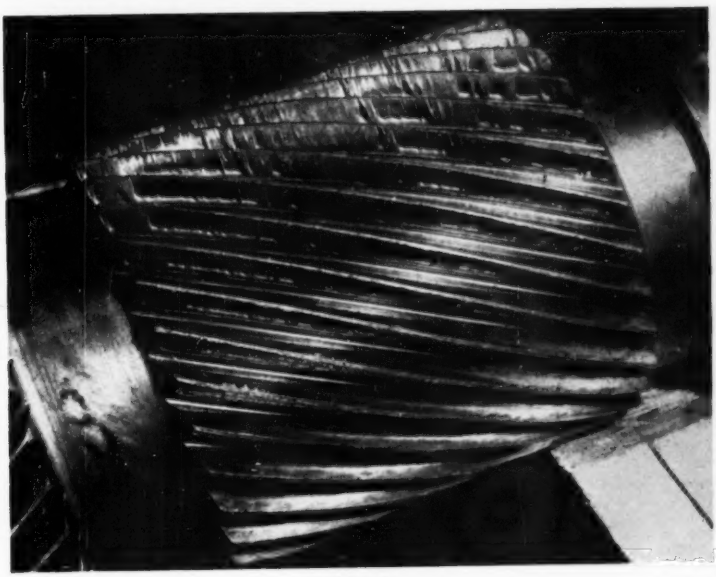

FIG 2

[*To face p.* 764.

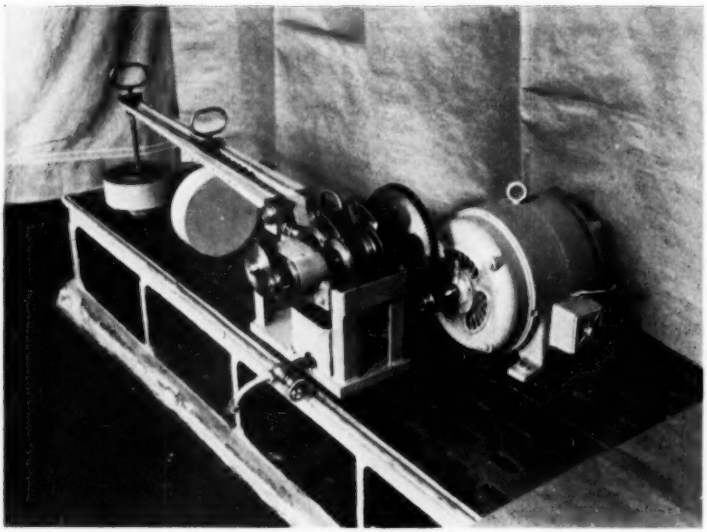

FIG 4

between a mating pair, and to simulate such a contact on easily produced test pieces machines were devised employing disks pressed into contact on their peripheries by a known adjustable load. By varying the relative motion of the disks any desired combination of slide–roll ratio can be obtained, and machines of this type have been used for many years to assess the properties of gear materials and lubricants.

The Testing Machines

A machine of this type is illustrated in Fig 3.

The disks *A* and *B* are pressed into peripheral contact by a load *W* acting on an arm *L* through the hinged carrier *C*. Both disks are keyed to shafts supported in roller bearings, and the shafts are connected by either gears or chain sprockets. The drive is taken from a spur pinion,

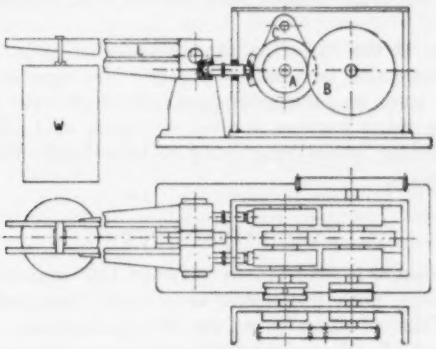

Fig 3

ARRANGEMENT OF 6-INCH SELF-ALIGNING DISK MACHINE

carried on the rotor shaft of a trunnion-mounted motor, engaging with a spur wheel on the shaft carrying the larger disk. To ensure equal disposition of load across the face-width of the disks the carrier is made in halves independently mounted on the hinge and the load arm is divided to apply a balanced thrust to each side.

In a smaller version of the machine employing relatively narrower face-widths, the self-aligning feature of the divided swinging frame was found unsatisfactory although the double load arm was retained.

The gears or sprockets connecting the disk shafts are mounted on their own shafts and bearings in a separate housing either attached to the main frame of the testing machine or bolted to a common bedplate. Connexion between the gear or sprocket shafts and the disk shafts is effected by Oldham couplings.

The oil being tested is partially contained in the body of the machine, and the larger disk is made to dip below the surface, the level being maintained by the open end of a pipe draining back to an auxiliary tank. A supplementary supply is provided by a pump feeding filtered oil from the tank through a pipeline to the zone of contact of the disks.

For tests using bronze and steel disks simulating worm-gear conditions,

long experience has shown that dip lubrication alone is entirely adequate, and in those cases the pumped supply is not provided. Fig 4 shows a disk machine with cover removed.

According to the British Standards method of gear-tooth loading, surface stress intensity is expressed in terms of the S_e value, which may be defined as

$$\frac{\text{Load per inch of line of contact}}{(\text{Relative radius of curvature})^{\frac{1}{2}}}$$

in p.s.i. units.

Such a disk machine, therefore, can be made to carry a wide range of S_e values by varying the load and effective face-width of the disks. Application of load may be made either by direct weights hung from the end of the arm or by a drum into which water is allowed to run at a known controlled rate, but the latter is preferred because it increases the applied load gradually.

Since S_e value is the criterion for intensity of gear-tooth pressure it follows that it may also be used to measure the capacity of a lubricant. For many years tests on numerous gear lubricants have been carried out in disk machines using various applied S_e values and selected conditions of rolling and sliding, simulating more or less closely those obtaining in line contacting gears.

Temperature Control

The oil temperature is maintained between 155° and 165° F. With the small disk machine, present practice is to apply heat, when required, to the underside of the oil sump by means of a gas burner. This has proved more reliable than electric immersion heaters and does not carbonize the oil. In the larger machine, however, long tubular electric immersion heaters are successfully utilized, largely because the application of heat is usually necessary for very short periods.

The greater need is generally to remove heat, and this is effected either by water-cooling coils or by air blast from a fan.

Procedure

(*a*) Materials used for the disks are chosen from the range normally employed for gears, and in common practice the small disk represents the pinion or worm and the large one the wheel. For worm gears, for instance, the combination is phosphor bronze and steel, the latter being usually casehardened, but, if the effect of a soft steel worm be required, it is manufactured from a heat-treated steel. Other material combinations may involve two direct hardened steels or two casehardened steels.

Heat treatment and hardness are carefully controlled, and although in the past the effect of physical structure on the performance of lubricants has not been measured extensively, this is now being investigated.

(*b*) Preparation of the disks is conducted with extreme care, and because all results are comparative, disks must be as nearly identical as it is possible to make them, both for concentricity and true cylindrical form.

Surface finish has an appreciable effect on results. Gear-teeth have a

wide variety of surface finishes, but after many trials it was decided to provide ground finishes of 10 to 25 micro-inches H_{max} on casehardening steels, 40 to 50 on bronze, and 60 to 80 on direct hardening steels. These are high-quality finishes and superior to those obtained on commercially produced gears, but in each case they permit optimum bedding-in of the surfaces during the initial rolling period when that is applied.

Operation of the Machines

One of the major difficulties is to ensure even distribution of load across the face-width of the disks, and the greatest care is taken when mounting them to ensure even contact by means of blue marking and rotation of the disks under a light load.

In earlier tests it was nearly always found that scuffing commenced near one edge of the contacting disk surfaces, suggesting an uneven load distribution across the line of contact, but with the measures taken in the latest machines the incidence of edge failure is much reduced.

Standard Tests

Experience over a number of years has resulted in the gradual evolution of standardized test procedures for the particular information required, and these are closely followed; deviation introduces unknown quantities which can destroy the essential comparative nature of disk-machine testing.

(a) *Coefficient of Friction.* For measuring coefficient of friction the large disk is bronze and the small one casehardened steel. A 6-inch centres machine is used with the effective face-width of the disk $\frac{3}{4}$ inch and, since the actual tests are normally of very short duration, preparation of the surfaces prior to taking readings is extremely important.

The desired surface finish of the bronze disk is obtained by giving the disks a prolonged running-in treatment with a motor speed of 1250 r.p.m. and a sprocket ratio of 48/47. As running continues with the oil temperature controlled to the desired value, the motor-torque readings fall until stability is reached. Readings are taken over a range of motor speeds, and each is repeated twice, giving three values at the selected points which, with an oil of normal behaviour, are virtually coincident. Tests are repeated with chain-sprocket ratios of 59/35 and 35/59 over the same range of speeds.

After each run, motor torques are obtained over the motor-speed range with the disks out of contact to determine oil churning, windage, and bearing-friction losses at each selected speed. These are deducted from the previous readings to give net torques required to overcome friction between the disks.

When testing any particular oil the machine is first filled with a standard paraffinic base oil of about 400 seconds Redwood viscosity at 140° F and the full range of observations made. It is then thoroughly cleaned out, using carbon tetrachloride as a final cleansing agent.

The procedure is repeated with the test oil, and again with the reference oil after a second dismantling and cleaning process, to ensure that stability has been maintained.

Even when a long series of tests involving numerous oils has been inter-

posed between the first and final sets of readings on the reference oil, agreement is remarkably consistent.

(b) *Scuffing*. When two contacting surfaces move in opposition at the line of contact conditions are unfavourable to the formation of hydrodynamic lubrication. This condition exists in worm gears, and few material combinations will run even under light loads without producing scuffing. Fortunately for the success of worm-gears a bronze/steel combination will function satisfactorily under relatively heavy loads, and this has led to the development of a procedure for testing lubricants under worm-gear conditions.

The 6-inch machine is again adopted with the active face-width of the disks reduced to $\frac{3}{8}$ inch to permit the application of higher loads and, using sprocket-and-chain connexion between the disk spindles with a constant motor speed, a gradually increasing load is applied until failure occurs. Disks which have previously been run-in and whose surfaces have reached stability are used, and failure is indicated by a sudden increase in motor torque.

With steel/steel material combinations the " slide–roll ratio " is necessarily small to conform to the condition actually obtaining in spur, helical, and bevel gears and to provide knowledge of the behaviour of oils lubricating steel gear pairs, the disks to simulate tooth surfaces moving in the same direction at the line of contact are driven by connecting their spindles with spur gears. For such an arrangement the slide–roll ratio of the faster-moving surface is regarded as positive and the other negative. This is similar to conditions in practice, where the slide–roll ratio changes from a minimum negative value near the root of a tooth to a maximum positive value at the tip, and disk-machine conditions can be selected to suit any desired point on the cycle of tooth engagement.

Tests are conducted on both the 3-inch and the 6-inch machines. A large amount of work has been carried out on the larger machine in connexion with turbine gear oils at the high speeds associated with that type of gear, but for normal comparative tests the smaller machine has generally been preferred, where both disks are made from En.30 steel heat treated to 100 tons p.s.i. with an active face-width of $\frac{3}{16}$ inch. Through-hardened material permits used disks to be re-conditioned repeatedly until diameters have been reduced by about $\frac{1}{8}$ inch. Bedding-in is not so easy as with bronze and steel pairs of disks, and it has been found beneficial to start with somewhat rougher contact surfaces.

A well-defined test procedure is closely followed to provide uniformity of conditions, and at least four pairs of disks are normally tested under any given conditions. The disks are run together at a rubbing speed of 185 ft/minute using a slide–roll ratio of $+0{\cdot}833$ on the large disk and $-5{\cdot}0$ on the small one. Load is uniformly increased from a starting value corresponding to a surface stress of 1000 until failure of the disk surfaces by scuffing or abrasive wear is produced, and with a " straight " mineral oil this occupies about 6 hours. The description " straight " is used advisedly, and refers to oils free from load-carrying improvers.

A group of representative results is first obtained from the standard reference oil when testing any series of lubricants, but owing to various inaccuracies and factors which are not yet clearly understood, some spread

in the results from any one group or between series carried out at different times seems inevitable. However, after making due allowance for this, a quite useful consistency remains.

In the 6-inch machine, for investigating turbine gear lubricants, numerous material combinations have been used for the disks, including case-hardened steels in addition to the more usual turbine gear steels. A procedure substantially similar to that employed with the smaller machine has been evolved, and this is closely followed.

Results and Applications of Results

Coefficient of friction is regarded as a measure of the lubricating qualities of an oil, and is of particular interest in worm-gear lubrication, since it affects the efficiency loss through tooth friction and consequently the running temperature. For spur, helical, and bevel gears tooth frictional loss is of secondary importance, but since in any list of oils selected for gear

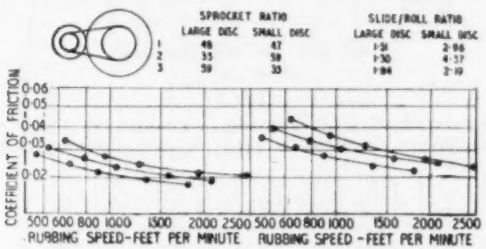

Fig 5 – Fig 6

COEFFICIENT OF FRICTION RESULTS FOR (FIG 5) A NORMAL GOOD OIL AND (FIG 6) AN UNSATISFACTORY OIL

lubrication any one may be used for all types of gear except hypoids, it is desirable to include those possessing a low coefficient of friction.

A typical set of curves is shown in Fig 5, and was obtained from a mineral oil of good lubricating quality, viscosity about 400 seconds Redwood at 140° F; Fig 6 illustrates results from an unsatisfactory oil of about 300 seconds.

Oils tend to exhibit a reduction in coefficient of friction as viscosity increases, but with modern oils the differences between oils of varying viscosity are not so marked as earlier results suggested. Even so, when testing an unknown oil, comparison is made with one of proved satisfactory service having approximately the same viscosity.

No oil is regarded as satisfactory if its mean coefficient of friction exceeds that of the standard reference oil by more than 10 per cent. This arbitrary value is based on results showing that abrasive wear of the bronze disk increases as the coefficient increases.

Bronze/steel scuffing results are intended to indicate the load-carrying capacity of worm-gear lubricants, and a typical coefficient of friction/S_e graph is shown in Fig 7, where the failure points are clearly defined. Visual examination of the disks afterwards reveals the transference of a film of bronze to the steel disk.

There is a certain amount of spread in the results obtained for various oils, but, generally speaking, low-viscosity oils consisting mainly of distillates have the lowest scuffing resistance. The majority of straight oils having viscosity values ranging from about 140 to 800 seconds Redwood I at 140° F show only a slight tendency to increasing capacity with viscosity. Exceptions to this rule are some of the oils produced to meet the L. 17 specification for rear-axle worm gears, and their greater resistance to breakdown may in some measure account for their success in service.

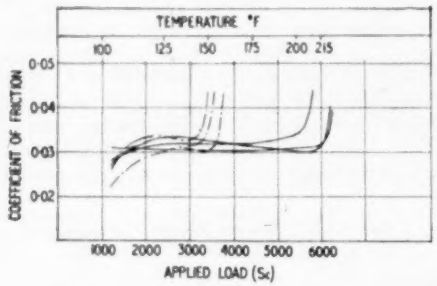

FIG 7

SCUFFING-TEST RESULTS ON WORM-GEAR LUBRICANTS 8-INCH-DIA DISK. 12% TIN BRONZE. 4-INCH-DIA DISK. CASE-HARDENED EN.34 STEEL

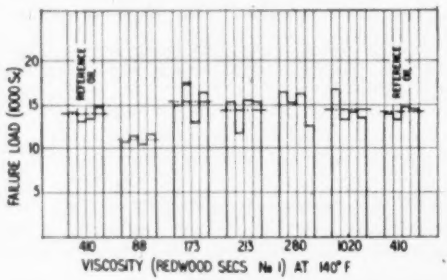

FIG 8

SCUFFING TEST RESULTS ON A RANGE OF GOOD GEAR LUBRICANTS FOR STEEL/STEEL GEAR APPLICATIONS

Extreme-pressure additives in worm-gear lubricants should be treated circumspectly; some which have been developed specially for the purpose are undoubtedly good, while results with others can be disastrous. Actually, in practice, an EP lubricant is usually unnecessary for a worm gear. When lubrication failure occurs in a rear-axle worm gear, only in exceptional circumstances can it be attributed to lack of load-carrying capacity of the oil used. Such conditions do sometimes occur, however, and instances are known of considerable trouble on vehicle drives where examination of the worm-gear teeth suggested lubrication failure. Disk-machine tests revealed a deficient load capacity in the oil being used, and the substitution of one known to have adequate capacity eliminated the trouble.

Steel/steel scuffing-test results are a later development of the bronze/steel

tests, and are perhaps more important, since cases of scuffing with steel/steel gears are still encountered. Fig 8 shows results from a typical series of straight mineral oils.

It will be noted that there is generally small benefit derived from viscosity, and all groups of oils show the same tendency. The light distillates have a lower value than oils of 140 to 1000 seconds Redwood viscosity at 140° F, but the latter are surprisingly uniform.

This does not mean that all oils behave in the manner indicated, because some have a quite definitely inferior capacity when measured by this type of test. Why this is so is not known, and more collaboration with lubricant technologists may provide an answer.

It should be emphasized that oils which do not reach the required standard may not necessarily be unsuitable for all gear applications, but the inference is that they have too low a factor of safety for universal application.

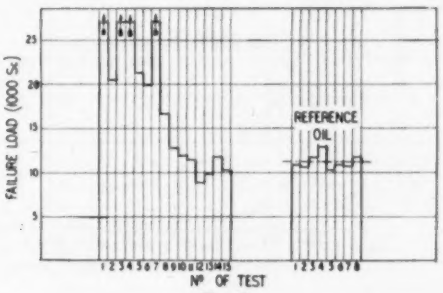

FIG 9

SCUFFING TEST RESULTS ON AN EP LUBRICANT

Oils containing extreme-pressure additives give results as illustrated in Fig 9. The disk tests indicate that they have very definitely enhanced load-carrying capacity, but also that in some instances such characteristics are transitory and the additive can be used or is destroyed during the tests. For that reason it has become a standard test procedure to run repeated tests to determine relative stability.

Such tests are interesting in so far that when extreme-pressure properties disappear the more or less objectionable odour emitted by the oil and the discoloration of the disks often associated with an extreme-pressure lubricant disappear at the same time, and the resultant oil behaves exactly as a straight mineral oil of equivalent viscosity. The test conditions are admittedly severe, and crowd into a few hours gear-teeth effects which normally occupy in service very much longer periods.

Some extreme-pressure oils retain their properties for as long as the tests continue, but whether this is the result of an increased percentage of additive or to its greater stability is another unresolved question.

For automotive applications many of the EP oils which exhibit a high S_c failure value yet lose it during the test are known to perform satisfactorily in vehicles, but such results should serve as a warning that a hypoid axle, for instance, needs a change of oil occasionally. Extreme-pressure oils are beginning to be adopted for gear units which are not associated with

automobiles, and there may be a large new opening in that direction. Naturally there is a tendency to choose for such units those oils which have the greatest stability, but if this is obtained by increasing the percentage of additive, other difficulties may ensue.

An interesting effect of rubbing speed on scuffing load is illustrated in Fig 10. Unfortunately, this work has not been pursued, but the results

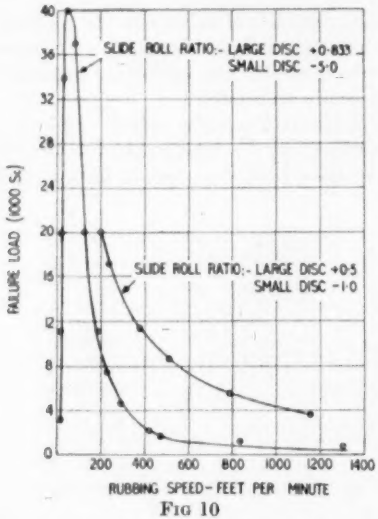

FIG 10

EFFECT OF SLIDING VELOCITY ON THE SCUFFING LOAD OF STEEL DISKS

indicate one of the many unknown features of gear lubrication which may usefully be explored.

From results of scuffing tests conducted on a limited number of oils it appears that within a rubbing-speed range of approximately 100 ft/minute to 2000 ft/minute there is a relationship between scuffing load and rubbing speed which can be expressed by the equation $S_c V^n = K$, where n and K are constants depending upon the slide–roll conditions, the lubricant, and the materials of the disks.

This appears to be the connecting link between disk-machine tests and the performance of actual gears.

SELECTION OF GEAR LUBRICANT

From the disk-test results it seemed logical to assume that the lubricant for any particular gear application could be chosen to suit the actual S_c value on the gears, provided adequate factors were introduced for operating temperature and maldistribution of load on the gear-teeth. Such a proposal had the attractive merit that, if the S_c value were small, a low-viscosity lubricant would provide protection against scuffing and by reducing turbulence would tend to increase the efficiency of a gear unit.

When applied to actual gear units, however, it was found, for slow-running gears particularly, that a light oil did not always ensure adequate

protection against scuffing in its various forms. Two other factors entered into the solution, one of which is expressed by viscosity of the lubricant and the other by the hardness of the gear materials. Viscosity introduces the element of time into the formation of the ultimate film of lubricant which separates the contacting surfaces, and hardness indicates, though inadequately perhaps, the ability of the gear materials to bed together. The resultant combination is embodied in Table I, which, although lacking

TABLE I

Spur, Helical and Bevel Gears

Lubricant Grade No.	1	2	3	4	5	6	7	8
$\frac{HS_e}{V}$	Up to 2·4	2·4 to 20	20 to 90	90 to 250	250 to 560	560 to 1100	1100 to 2000	above 2000

Worm Gears

Lubricant Grade No.	3	4	5	6	7	8
$\frac{100\,S_e}{V}$	Up to 5	5 to 14	14 to 30	30 to 60	60 to 100	above 100

S_e = actual surface stress criterion for gear-teeth.
H = D.P.H. number for the softer member of a gear pair.
V = pitch-line speed in feet per minute.

many of the refinements possible from a more extensive knowledge of the mechanics of gear lubrication, meets requirements for commercial use. In any case, the selection of a suitable gear lubricant should avoid the necessity for more than a minimum of calculation.

The grade numbers included in Table I refer to the approximate viscosity at 140° F and are listed in Table II. At one time various other physical

TABLE II

Lubricant Grade No.	1	2	3	4	5	6	7	7T	8
Approx visc Red. I at 140° F, sec . . .	90	110	140	200	275	400	600	600 to 1000	1000

7T applies to vehicle gear-box and rear-axle lubricants.

properties were specified, but with modern gear lubricants it was found that these had lost any significance they may once have possessed. For some years past the suitability of an oil for gear lubrication has been successfully assessed on the results of the tests outlined. By no means all oils having the requisite viscosity satisfy disk-machine tests, which admittedly are of an exacting nature, and some oils may perform adequately as gear lubricants in particular applications yet fail to meet test

requirements. But since any published list of approved lubricants must apply to gear drives loaded up to their full capacity, and particularly to gears designed for short-life requirements where tooth-loading conditions are much more severe than for the normal industrial drive, there must be no doubt that any of the oils listed will meet these conditions. Typical examples of gear-lubricant selection are shown in Table III.

TABLE III

Typical Examples of Gear-lubricant Selection

Application	Type of gear	Designed life hr	S_c	V ft/min	H (D.P.H. No.)	Oil grade No.
Pump drive	Spiral bevel	52,000	675	3050	300	3
Industrial	Worm gears	26,000	250	1640	—	5
Test plant	Double helical	1,000	1500	2400	300	4
Test plant	Double helical	3,000	665	7300	210	2
Industrial	Worm gears	26,000	890	85	—	8
Industrial	Double helical	52,000	440	695	255	4
Double reduction	Spiral bevel	52,000	900	1790	750	5 *

* In such cases the higher grade is used throughout.

Worm gears are particularly sensitive to the quality of the lubricant, and since friction loss affects the running temperature, to obtain a temperature rise within the designed range a maximum permissible coefficient of friction must be arbitrarily chosen. A high coefficient of friction has been found to promote rapid wear of the bronze wheel.

Vehicle worm gears are generally much more heavily loaded than industrial gears, and consequently both coefficient of friction and load capacity are important. In fact, at the high rubbing speeds encountered in some applications there is a tendency for even the best straight mineral oils to break down momentarily, although the worm is submerged, and permit scuffing. Fortunately, in practice a high tin bronze appears to have the attribute of recovering when the severe load/rubbing-speed conditions are alleviated, but an oil deficient in load capacity seems to break down at an appreciably lower rubbing speed, and excessive temperature combined with heavy wear result.

These remarks touch only the fringe of a vast and extremely important subject and omit entirely to deal with the mechanics of gear lubrication. Much work remains to be done. Perhaps the approach to the subject through disk-machine testing is incorrect; it certainly has many errors and omissions. A more comprehensive tie-up with results from tests on actual gears is needed, because although some results from the two methods are agreeably close, there are many unresolved discrepancies with others.

Such problems must be left for future work to solve, and in the meantime gears must continue to be adequately lubricated using the knowledge available.

ACKNOWLEDGMENTS

The author acknowledges his indebtedness to Messrs. David Brown & Sons (Huddersfield) Ltd. for permission to use information based on their methods and practice.

SERVICE TESTS IN REAR AXLES OF BUSES AND TROLLEY-BUSES

By H. E. Styles * and A. T. Wilford * (Fellow)

Service Testing

In selecting lubricants for specific applications, London Transport places great reliance on service tests. Even if well-established performance tests are available, there is always a doubt about the degree of correlation with the particular conditions encountered in service. It is considered necessary, therefore, to confirm that a new type of lubricant is better than, or at least equal to, the " standard " grade in current use before making a change, the effect of which will be reflected in the running and maintenance of thousands of vehicles. Where, as is so often the case, the information about a lubricant is confined to physical and chemical characteristics, service testing becomes imperative.

Because of the non-existence of suitable performance tests, or through lack of confidence in their ability to predict behaviour in practical use, it is usual for service tests to be started on a small scale and to await experience before expanding their scope. The suitability or otherwise of the lubricant undergoing test is assessed by inspection of the units concerned after a period of time, or by observing the life of the units between successive overhauls. In either case comparison is made with similar units lubricated with " standard " oil and run under the same or closely similar conditions. In some instances it is sufficient to base conclusions upon the condition of the lubricant after successive periods of use, as compared with " standard " lubricant after similar periods of use; but here again it is necessary to ensure that the groups of vehicles in which the " experimental " and " standard " lubricants are employed, are operated under similar conditions.

The difficulties in conducting tests so that the vehicles concerned are operated under similar conditions are much greater than might be supposed. The selection of vehicles, all of a particular type, and fitted with units—engine, gearbox, and rear axle—of the same design, presents no problem. It is essential that the units should be of the same age, preferably new or newly overhauled, a requirement which may render it necessary to transfer vehicles from one garage to another, but this can be done without undue trouble. It must also be possible to identify the units at any time during the course of the test; a well-tried system of labelling a unit and identifying the vehicle to which it is fitted not only serves to indicate which units must be lubricated with the experimental oil but also ensures that a high percentage of units involved in a particular test is kept under observation throughout life. The real difficulties in service testing arise from the fact that operating conditions differ from garage to garage, on each of the routes served by a particular garage, and even for individual vehicles running on a particular route. This statement may seem far-fetched, but it has been

* London Transport Executive.

thoroughly confirmed in the course of numerous investigations into vehicle fuel consumption, when it is found that the consumption exhibited by a particular vehicle on a given route varies to a significant degree according to the precise position of the vehicle in the route schedule. The importance of this observation from the point of view of comparative testing will be appreciated when it is added that for operating reasons, vehicles may remain allocated to a particular route and even to the same position in the route schedule for a period of two months or more. In normal circumstances, therefore, vehicles must be run for a very considerable mileage before they can be regarded as having operated at random, which is the only basis upon which two or more groups can be safely compared. (The alternative of operating groups of vehicles under the same set of fixed conditions cannot possibly be achieved except on a proving ground such as that established by the Motor Industries Research Association.) The "experimental" and "standard" groups are preferably located in one garage, and where this is not possible or if the test has been expanded to garage-fleet scale, great care has to be exercised in selecting two or more garages at which operating conditions are closely comparable.

In addition to complications arising from variations in conditions of operation, it is also necessary to take cognizance of the fact that no two mechanical units can be regarded as precisely identical. For this reason alone it is necessary to test a number of units in order to obtain a measure of the variance between them, and in the initial selection process, in planning the test schedule, and in reviewing the data subsequently obtained, full use is made of statistical techniques.

Provided that the test has been adequately planned and that the plan has been followed, experience indicates that it is possible to rate an engine lubricating oil by the criterion of average engine life between overhauls, though groups of several hundred engines may have to be compared before a convincing answer is obtained.[1, 2] A similar criterion may be employed in evaluating a lubricant for pre-selective gearboxes, though in this instance the information can be more conveniently obtained from examination of samples of the used oil taken at regular intervals and, if necessary, over a period of time equal to that of the average life of the units when using the "standard" lubricant. Relatively little success has been obtained in attempts at assessing the suitability of an oil by inspection of the units after a period of service significantly less than the average life of the units. A striking example of the trouble which may eventually be encountered through drawing conclusions from tests carried out for too short a period or involving an inadequate number of vehicles, or both, was given by one of the authors some five years ago in a paper dealing with lubrication of pre-selective gearboxes.[3] From experiences of this sort it has been learned to mistrust short-term tests involving only a few vehicles, and the present tendency is to aim at obtaining mass data, the significance of which can be tested by statistical methods.

Tests with Uninhibited Rear-axle Oils

The technique of service testing outlined in the foregoing, though successful in the selection of lubricants for C.I. engines and for pre-selective

gearboxes, has until recently, failed to give satisfaction when applied to rear-axle lubricants. Over a period of several years up to 1945, at least ten different grades of oil were tested in rear axles of buses, but in the majority of cases inconclusive results were obtained; in one or two instances in which indications were favourable, these were not confirmed when the tests were repeated or extended in scope. The lubricants tested during this period included castor oil, compounded oils, lead-soap lubricants, filtered cylinder oils of both low and high viscosity index, and EP lubricants; excluding castor oil, viscosities ranged between about 113 and 280 centistokes (460 and 1140 sec Redwood) at 140° F. Castor oil appeared to be relatively satisfactory as a lubricant, but the oil seals which were in use when the test was made were not capable of preventing leakage; since that time castor oil has become prohibitively expensive. Of the other lubricants tested, including the asphaltic-base oil in "standard" use, all of them became severely oxidized after some 12,000 miles in service, the deterioration being evidenced by excessive though very variable increase in viscosity.

During the years that these tests were in progress, rear axles were removed for overhaul on a fixed-mileage basis, and the performance of the lubricants was judged by the degree to which the worm-shaft and worm-wheel were worn. This varied to a considerable extent, even within a group of units from vehicles at a particular garage, but was always relatively heavy, the bronze worm-wheels being severely flaked and coarsely pitted. It was this variability that defeated attempts to differentiate one lubricant from another, and it was concluded that the problem was largely a mechanical one which probably could not be overcome by selection of lubricant alone, though, in parenthesis, it may be remarked that the oil industry does not appear to have given the same attention to lubricants for worm-driven axles as it has to lubricants for hypoid gears and other heavy-duty mechanisms.

During the course of the foregoing tests, however, the conclusion was reached that an oil of rather lower viscosity than had hitherto been employed might be worth while adopting for rear-axle lubrication; it was also thought that a less asphaltic type of oil might prove more stable. These changes were put into effect for the post-war fleet of buses, in which provision was made for a rear axle of more adequate dimensions. The oil adopted was of high viscosity index with a viscosity of about 150 centistokes at 140° F, specification details being given in Table I. A similar

TABLE I

Characteristics of Uninhibited Rear-axle Oil

Specific gravity	Not specified
Kinematic visc at 140° F	135–155 cs
Kinematic visc at 210° F	30·0 cs min
Redwood visc at 140° F	550–625 sec
Redwood visc at 210° F	126 sec min
V.I.	95 min
Pour point	20° F max
Closed flash point	475° F min
Organic acidity	0·01 mg KOH/g max
Ash	0·005 per cent—max
Oxidation characteristics:	
Visc ratio (at 140° F)	1·5 max
Asphaltenes	0·05 per cent—max

lubricant had been used for some time in trolley-bus rear axles with moderately successful results, though it was necessary to change it at 15,000-mile intervals on account of marked increase in viscosity. It was disappointing, though not perhaps surprising, to find that the oil exhibited no better stability when used in the rear axles of buses. This will be seen from the figures given in Table II, the data being derived from the examina-

TABLE II

Average Characteristics of Uninhibited Oil after Use in Rear Axles of Trolley-buses and Buses

Vehicle type	Mileage between oil changes	Characteristics of oil at oil change	
		Visc, cs at 140° F	Acidity, mg KOH/g
Trolley-bus . . .	15,000	324	2·0
Bus (C.I.-engined) . .	18,000	303	10·4
(Average characteristics of fresh oil		146	Negligible)

tion of a large number of used oils from both trolley-buses and post-war buses.

TESTS WITH OXIDATION-INHIBITED REAR-AXLE OILS

It had long been appreciated that an increase in the viscosity of the rear-axle oil is objectionable in that it leads to an increase in power losses and in consequence, in fuel consumption; it may also result in greater wear and tear of the gears, particularly at low atmospheric temperatures when " channelling " may occur. Experience in the lubrication of pre-selective gearboxes had already shown that by the use of a suitable base oil containing an appropriate oxidation inhibitor, increase in viscosity of the lubricant during use could for all practical purposes be eliminated. Arrangements were therefore made with one of London Transport's suppliers, and at a later date, with several others, to provide a rear-axle oil in general compliance with the Executive's specification (Table I), but containing an oxidation inhibitor. The nature and concentration of the inhibitor employed were left to the discretion of the supplier. Service tests were carried out with experimental batches of the respective oils.

The primary object of the tests was to select lubricants which would remain stable over a period equivalent to at least 15,000 to 18,000 miles and preferably for a much longer mileage. London Transport was not concerned at this stage with determining the effect of the lubricants on worm-shafts and worm-wheels, it being reasonably assumed that the addition of an oxidation inhibitor to a known base oil would not lead to increased wear. It was decided, therefore, to commence tests with one of the oils—containing an alkylated-phenol-type inhibitor—on a relatively large scale, all trolley-buses at two depots being involved. (The same oxidation-inhibited oil, but containing also an anti-foaming agent, was tested at a third depot; no special benefit appeared to derive from the presence of the second additive, and the test was eventually abandoned.)

Having regard to the object of the tests, it was possible to assess the

performance of the oil by carrying out determinations of acidity and viscosity on samples drained from the axle pots after a period of use. It was only necessary to reiterate the standing instruction governing oil changes—that axle pots must be drained when the oil is hot, *i.e.*, immediately the vehicle returns to depot after a period in service—and to lay down that the oil should be collected in a clean container, from which the sample for laboratory examination was taken after thorough stirring. In the first series of tests the experimental oil was changed at intervals of 15,000 miles. Its condition indicated that it could probably be retained in use for a longer mileage; further tests were therefore carried out in which the oil-change periods were extended to 23,000, 34,000, and finally 45,000 miles. The average characteristics of all samples representative of the four progressively longer periods of use are given in Table III.

TABLE III

Average Characteristics of Inhibited Oil after Use in Rear Axles of Trolley-buses

Mileage between oil changes	Characteristics of oil at oil change	
	Visc, cs at 140° F	Acidity, mg KOH/g
0 (fresh oil)	147	Negligible
15,000	178	0·7
23,000	175	0·9
34,000	198	1·6
45,000	233	2·2

It must be admitted that the average figures quoted in Table III conceal a fair amount of variability. They clearly indicate, however, that even after 45,000 miles the oxidation-inhibited oil is in much better condition than is the corresponding uninhibited oil after only 15,000 miles use. It would also appear that the inhibited oil exhibits a tendency towards an accelerated rate of viscosity increase between 34,000 and 45,000 miles. This observation suggested that prolonged use of the oil would be likely to have an adverse effect on power consumption, and led to the conclusion that it would be unwise to extend the oil-change period beyond 34,000 miles; the need to prevent excessive accumulation of metallic debris within the differentials was also kept in mind.

The only tangible benefit obtained from the use of an oxidation-inhibited oil in trolley-bus rear axles is, therefore, an extension of the oil-change period to rather more than double the mileage at which the uninhibited oil was changed, though this has effected some economies in both lubricant and labour costs. But the much better condition of the uninhibited oil during its period of use must lead to a reduction in power consumption, and is likely also to contribute to a reduction to wear; at the moment, however, neither of these possible savings can be assessed.

The same oxidation-inhibited oil has also been tested in rear axles of buses, and here again there is satisfactory evidence that it permits an extension of the oil-change period from 18,000 to 36,000 miles, with possible additional benefits in respect of reduced power consumption and

reduced wear. Figures showing the average characteristics of the used oil at the two mileages are given in Table IV.

TABLE IV

Average Characteristics of Inhibited Oil after Use in Rear Axles of Buses

Mileage between oil changes	Characteristics of oil at oil-change	
	Visc, cs at 140° F	Acidity, mg KOH/g
0 (fresh oil)	147	Negligible
18,000	164	1·9
36,000	171	2·4

Mention has already been made of the variability of the data obtained from the used oil samples. This is illustrated by the mean viscosity and acidity figures given in Table V, together with the corresponding standard

TABLE V

Characteristics of Inhibited Oil after Use in Rear Axles of Trolley-buses at Two Depots

Depot	A (North of Thames)		B (South of Thames)	
	Condition of oil at oil-change			
	After 34,000 miles	After 45,000 miles	After 34,000 miles	After 45,000 miles
Mean visc, cs at 140° F .	198	207	199	276
Standard deviation . .	21	26	39	179
Mean acidity, mg KOH/g .	1·3	1·7	2·2	2·3
Standard deviation . .	0·51	0·56	0·87	0·78
No. of samples . .	30	26	12	16

deviations. From these figures it can be deduced that at depot A, the increase in viscosity between 34,000 and 45,000 miles is not significant; the increase in acidity is, however, significant of a small, though real change. In the case of depot B, the large increase in viscosity between 34,000 and 45,000 miles is nevertheless not significant because of wide variability of the individual samples. Comparing the 45,000-mile samples from the respective depots, statistical tests show that the mean difference of 69 centistokes is just significant of a greater increase in the viscosity of the oil when used at depot B, while the acidity of the oil from that depot is very significantly greater than that from depot A.

Apart from the bald statement that the difference in the rate and degree of deterioration of the rear-axle oil in trolley-buses at depots A and B respectively is due to a difference in operating conditions, no explanation is offered; nor can any definite reason be given for the observation that on the average, rear-axle oil from the trolley-buses involved in the tests showed a greater increase in viscosity but lower increase in acidity than did the same oil, whether plain or inhibited, from buses after similar mileage. These differences may have resulted merely from differences between

conditions of service of the buses and trolley-buses, or they may reflect real dissimilarity between the way in which oil deteriorates in the axles of the respective types of vehicle.

Service tests on a somewhat smaller scale have also been carried out on buses with rear-axle oils containing other types of oxidation inhibitors. In addition to an alkylated-phenol-type of inhibitor, oils containing phosphorus, phosphorus and sulphur, and amine-type inhibitors respectively, have also proved much superior to the uninhibited oil. In the case of one amine-type inhibitor at least, the concentration appears to be critical in that an oil containing 0·5 per cent exhibited a negligible increase in viscosity after 18,000 miles, with an acidity of 2·6 mg KOH/g, whereas the same base oil with only 0·25 per cent of the inhibitor exhibited a viscosity 250 centistokes at 140° F and an acidity of 3·2 mg KOH/g after a similar period of use. In both cases the figures represent the mean of at least twelve samples.

It is of interest to note that in the case of another oil, incorporating a phosphorus-containing inhibitor, one series of tests indicated the average viscosity at 140° F of the used oil after 18,000 miles service to be some 15 centistokes below that of the new oil. Whilst this observation was not confirmed in subsequent tests with the oil in question, similar evidence has been obtained occasionally in the past, and the effect can presumably be attributed to rupture of large oil molecules under the very severe local stresses which occur in heavily loaded worm-drives. It may well be that the effect occurs more frequently, but is normally masked by simultaneous thickening due to oxidation. Alternatively, oils showing such behaviour may be ones containing added viscosity improvers, the breakdown of which causes the observed reduction in viscosity.

Problems Outstanding

It would seem that oxidation-inhibited oil provides the answer to the problem of excessive thickening of rear-axle lubricant during use, but the problem now to be faced is that of compatibility of rear-axle oils containing different types of inhibitors. There is no difficulty in confining a particular oil to one garage or even a group of garages, but doubts arise when for operating reasons vehicles are transferred to garages at which oils with different types of inhibitors may be in use. At the moment arrangements are being made for the axle pots to be drained as soon as possible after a vehicle has been transferred, but this can only be regarded as a temporary expedient. Service tests to determine the compatibility of all possible mixtures of four or perhaps more types of inhibited oils present almost insuperable difficulties, and failing the development of a reliable laboratory test, it may eventually be necessary to use only inhibited oils in which the additives are known to be compatible.

It is not anticipated that adoption of inhibited oils will markedly influence the life obtainable from rear axles between overhauls, and there would seem to be a considerable field for further research into the whole problem of reducing the excessive wear experienced with the worm-gear drives normally employed on public-service vehicles. Tests are at present in hand with one particular oil containing additives which it is hoped will

reduce such wear, but it is as yet too early to say whether or not successful results will be obtained.

Acknowledgment

The authors express their thanks to the London Transport Executive for permission both to present this paper and to make full use of experimental records in the preparation of the paper.

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Discussion

J. R. Hopkins: Mansion, in his paper in Part I of the symposium, referred to the hardness of gears and stated that there was no systematic variation of scuffing loads with surface hardness over the range of 360 to 840 V.P.N. Later in the paper he stated that nitrided gears have a much higher scuffing load.

It occurs to me that the essence of success when using gears as a means of rating oils, is that there must be great consistency in the accuracy of the gears used. If it is true to say that softer gears can be used, there are other methods available to-day for producing gears which would be greatly to the advantage of the users in that they would be cheaper to manufacture and might give more consistent results.

It is admitted that in general it is desirable to use case-hardened steels, since they are more generally used in industry, but if a direct-hardening steel could be used, not exceeding 360 V.P.N., it would be possible to shave the gears. In explanation I would say that, having once made a master set of shaving cutters for this work, it is possible to obtain extremely consistent results, quite equal to those obtained in good-class grinding practice. A finish as fine as 12 micro inches R.M.S. can be obtained. Having one master tool, it would be possible to shave perhaps as many as 1000 gears and to obtain very consistent results, so that all laboratories would be in a position to have all specimen test gears made from one exact source.

The whole essence of the shaving principle is that the tool itself transfers its accuracy to the gears, and I think this matter is worthy of consideration. Obviously in the first instance it should be done only on a very small scale, to ascertain its reliability, and I feel that if this system should prove successful it would enhance the use of this equipment as a means of obtaining oil ratings.

The question of profile modification is unquestionably highly important. Various road and other test results have been obtained from time to time and, although the results are not conclusive, there is evidence that the variation in many of the results has been caused by very small inaccuracies in the gears, so that there seems some case for considering the possibility of using slightly softer steels and developing other processes for producing these gears, which are more economic.

V. H. Brix : On the whole I think we should accept, in general, the results obtained with the IAE-type machine, merely because it is a gear machine. Definite trends are visible. In the first place there are the effects of various oils, naphthenic, paraffinic, and so on; and in the second place there are the effects of surface materials and other variables. As has been pointed out, however, it is very difficult to obtain really consistent test pieces, and the need is for a testing machine which will do what the IAE machine does, but more easily.

I do not know, but doubt, whether the four-ball or the two-ball machines or any other sliding-disk or rolling-disk machines have given sufficient correlation with the IAE-type machine. I obtained some results which did give correlation, some time ago at Messrs Rolls Royce, from a very simple type of machine which could be operated by a non-technical person, and on which eight or more tests could be made in a day; the consistency was remarkable. We did about 300 tests, using all varieties of oils. Out of that number I can only remember one rogue result which did not agree with our IAE test, and that was on the question of surface finish (we tried super finishing of the surfaces and obtained good results, and the IAE machine results did not agree).

On the other hand, we had general correlation with Mansion's results. In collaboration with the Ministry of Supply we found that a naphthenic oil having a low viscosity index was very much better than a paraffinic oil. We could also discriminate between steels; for instance, case-hardened nickel–chromium steel was slightly better than a case-hardened nickel steel.

Thirdly, on two or three occasions where piston-ring scuffing occurred during bench engine tests we found that the oils gave consistently low ratings, and in one test there was a bad case of gear scuffing. The oil was changed to one which gave higher ratings, and no further engine trouble was reported.

Apart from that, we found that the type of oil which was used when we experienced this bad scuffing was supplied by one particular manufacturer. The same oil gave trouble in private cars, but the trouble was soon cured by varying the additives.

The machine is purely empirical and open to criticism from the gear-design point of view. It consists merely of a " roller " element reciprocating on a sliding element, so that there is combined rolling and sliding. Unfortunately it has infinite specific sliding at the ends of the stroke. But I do recommend a little more investigation of it.

A. L. Temby : I am interested in the disparity as well as in the agreement between the results of the various rig tests in the determination of the load-bearing capacity of lubricants. So often the users accept the results of rig tests as irrefutable evidence that an oil is satisfactory or otherwise for a particular job; but in general it is not necessarily so. Is there widespread agreement as to the absolute value of the results of tests in any of the rigs described in the papers under discussion?

Apparently the IAE rig is adjudged the most satisfactory, but only for rating oils for propeller reduction gears. I am led to suppose that for some other purposes the rig may be better, or at any rate no worse, than others. A good deal of work must be done, not only on rigs, but also on other

fundamental aspects before any rig test can be used as a criterion of the service performance of oils.

On the question of back-axle oil, it is very encouraging indeed to hear that the Vanguard axle is proving a useful alternative to the Chevrolet axle on the 2–105 oil; but it would be very interesting if someone could give data indicating the relative severity of operating conditions in a variety of axles in current production. The oil-change periods recommended by various manufacturers vary from about 5000 to about 12,000 miles for passenger cars, and one wonders whether those differences reflect the relative severity of the operating conditions in the axles.

PROFESSOR E. MCEWEN: With regard to Greenwood and Morton's paper, where the work appears to show a definite dynamic load equivalent to 35 lb on the IAE rig adding to the nominal load, I should like to know whether a stress calculation has been made, for example, by the method suggested by Tuplin.*

In Cameron's paper (in Part I) there is a heat factor which includes, amongst other terms :—

$$\left\{1 + 2\left(\frac{V_1 - V_2}{V_1 + V_2}\right)^2\right\}$$

If that is applied to Fig 10 of Watson's paper (in Part II) the values for these parameters are respectively 0·7 and one-third, which gives a ratio of this whole factor of about 5 : 3. If, then, allowance is made for the fact that Watson's results are plotted on the basis of sliding velocity, it is found that for the same rolling velocity the failure loads appear to be roughly the ratio of this factor, which appears in Cameron's total heat input. If that is generally true and it is not specifically restricted to Watson's results, something has been achieved. Has anybody any further data of the general nature of this Fig 10?

A. J. LAMBERT: My view of the application of gear test rigs is that they should reproduce, in large measure, the actual operating conditions. It is unlikely that any one test rig will have many applications. It seems reasonable to expect that gears should be used to test gear lubricants. The IAE rig would be a likely choice of apparatus for testing lubricants to be used with spur and possibly helical gears.

The paper by Towle does indicate that a practical approach has been made to the problem of testing gear lubricants, especially EP lubricants as used with hypoid gears.

There is some indication that test rigs, which do not employ gears but which attempt to reproduce gear-tooth action, do obtain doubtful correlation when base oils are used. Lubricants which contain EP additives do not appear to behave according to any particular rule.

A gear designer has a wide field of choice in gear ratios, tooth-face width, pitch, helix angle, etc., and it is possible that a particular lubricant will work well with one design and badly with another.

G. W. SEARS: In comparing the four-ball and road-test wear results, Bingham and Withers state that the considerable differences in wear rate

* *Proc. Instn. mech. Engrs, Lond.*, 1950, **163**, 162.

between the several cars used have prevented any "direct approach to a more useful correlation," and that the difficulty will be avoided in future tests by use of a reference oil of a kind suitable for both special and hypoid bevels.

In the first place I contend that there is no real difficulty. For if it can be shown that a given change in the four-ball test rating of an oil corresponds to a fixed change in the rate of wear on the road no matter which car is involved, then correlation is established; and, moreover, if this relationship for oils suitable for spiral bevels is shown to be equally applicable to those suitable for hypoid bevels, then no difficulty arises from the general differences in wear rate of the various cars. Correlation, in fact, is established by changes in wear rate, not by the actual rate of wear itself.

With the exception of the results on Oil 1, this is precisely the situation in Bingham and Withers' data. Because of the arrangement of the oils in the cars, correlations can only be established in the first instance in these groups of oils, namely :—

	Group 1 (SAE 140)	Group 2 (SAE 90)	Group 3 (SAE 90)
Oil Nos.	1	3	4C
	2A	4A	4D
	2B	4B	6
	5A		

It may be shown that if Oil 1 is ignored, then there is no reason to believe that the correlations for these three groups differ, apart from those general differences in wear rate which may presumably be attributed to the car groups. Such differences may therefore be eliminated from the data, and the estimates of mean road rates of wear after this adjustment are given in Table D and plotted against the four-ball results in Fig 10.

TABLE D

Oil	Mean rate of wear	
	Road tests, g/mile	Four-ball tests, mm/min
2A	0·000021	0·00019
6	0·000036	0·00039
5A	0·000029	0·00049
4A	0·000061	0·00080
3	0·000056	0·00100
4B	0·000115	0·00150
2B	0·000119	0·00160
4C	0·000113	0·00180
4D	0·000119	0·00220
1	0·000036	0·00240

With the exception of that for Oil 1, it can be shown that there is no reason to believe that any of the deviations from the line are not in accordance with the errors to be expected from the road and four-ball test procedures. The correlation is in fact remarkably good, and with the exception of Oil 1, could represent an exact relationship between the two test methods.

Secondly, it is noted that three of the papers given in Part II refer to the use of, or to the intended use of, a reference oil, as if this were a universal panacea for poor precision. This is far from being the case, but unfortunately it is not possible to generalize on whether reference-oil procedures are or are not a " good thing." In certain situations they may improve matters appreciably, and in others they will be correspondingly less efficient than the best alternative approach. A full discussion covering all possible types of situation cannot be given here, but in any particular situation the best approach can be decided on statistical grounds, provided a knowledge of the various components of variation is available. In the case of Bingham and Withers' work, a great deal of experimental effort would have been expended on the reference oil merely to confirm that the differences between the correlations were in line with the differences between the car groups, and the gain in reliability of the correlations would not have been in proportion to the additional effort required.

If I may be permitted to draw a moral from my own remarks, then I suggest that, in this case at least, a competent statistician would have been a better expedient than the best use of a reference oil.

Turning now to the paper by Greenwood and Morton, it does not appear to be widely recognized as yet that the repeatability of a test procedure does not necessarily bear any relation to its useful precision. Repeatability is simply a measure of the agreement that can be obtained in consecutive duplicate results on the same oil and test rig, and therefore represents the best possible apparent precision that can be obtained. That this degree of precision is in some cases achieved only by repeating the " mistakes " made in the previous determination is of no consequence, since the repeatability is only of use in checking that no gross blunder has been made. The useful precision, on the other hand, relates to the ease with which a set of different oils can be rated in the correct order, and in the case of the IAE 3¼-inch gear rig is known to be appreciably larger than, and quite different from, the best repeatability that can be obtained. This is the explanation of the apparent discrepancy between the precision data given by Greenwood and Morton and those quoted in the paper by the Mechanical Tests of Lubricants Panel.

The precision data quoted by Greenwood and Morton are therefore quite irrelevant to the useful precision of the test procedure. Even if this were not the case, the analysis of the results is incorrect at several points. I will not attempt to detail all the criticisms which would be made, since I regard the precision data as misleading, but two examples will serve to indicate the unsatisfactory nature of the analysis.

The authors' Table II purports to show that variability using any side of any gear pair is 28 per cent greater than that encountered in tests on opposite sides of the same gear pair. The data presented for " all sides " variability, however, consist partly of variations from side to side of the same pair and partly of variations from pair to pair. These separate estimates have apparently been pooled before checking whether such pooling was justified. Moreover, the authors do not give the numbers of degrees of freedom appropriate to their estimates, so that it is impossible to check this statement. Since the " all sides " variability is an average of an unknown number of " side-to-side " parts and an unknown number of

" gear-pair-to-gear-pair " parts, it is evident that provided enough " side-to-side " parts are taken, the averages quoted for " all-sides " variation can be made as near as we like to the " side-to-side " variation. Consequently, the stated increase of 28 per cent has no meaning.

Again, the results given in Table III consist largely of those subsequently presented in Table IV, but it is found that the authors have added in Table III some additional results, presumably on other oils, to give the data quoted in the " All results " column. By reference to Table IV I find that these additional results on Gears 34X and 34Y had standard

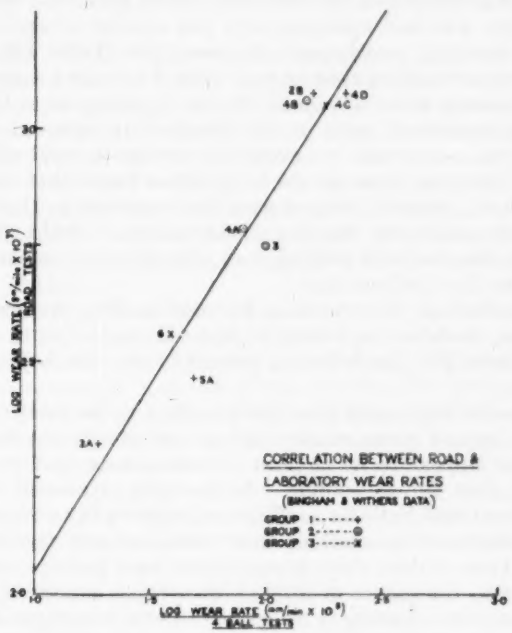

FIG 10

deviations of 13·3 (9 degrees of freedom), and 13·6 (13 degrees of freedom) respectively, and it can be shown that there is no justification for adding such data to those of Table IV.

On a more general note, I naturally welcome the increasing use of statistical techniques in the interpretation of gear lubrication work generally. But I suggest that in presenting the results of such analyses, the experimenter should either give a bare statement of his conclusions without presenting the statistical arguments, or preferably he should present a complete summary of the data, so as to allow future investigators the full benefit of his work with opportunity to satisfy themselves as to the validity of his own conclusions. Greenwood and Morton have fallen [*sic*] between these two stools.

PROFESSOR H. BLOK : The Mechanical Tests of Lubricants Panel rightly points out that, according to Table II, the reduction in scuffing loads obtained by substituting the standard 15/16 toothed gears by 12/13 gears, is disappointingly small. It is suspected, however, that a really worthwhile reduction can be achieved by using gears that have as small a number of teeth as possible, *e.g.*, 8/9. Further, such gears might well extend the range of rating scuffing performance as compared with the range of the present gears of the IAE machine, the reason being that a substantial increase would probably be attainable in the loads at which pitting occurs.

In the discussion by Sears it has been pointed out that there is a remarkably good correlation between wear results from road tests and those obtained in the four-ball machine, with the notable exception, however, of oil No. 1, the only non-hypoid oil tested (see Table III and Sears's figure). It may be added that around 1935 I obtained a similarly good correlation between wear of a small Mathis hypoid gear in long-duration dynamometer tests and wear in the four-ball machine at low loads.* Again there was sometimes an exception for non-hypoid oils; from an inspection of the wear scars on the balls it was found that with such oils mild scuffing or a related form of wear had occurred in the tests on the four-ball-machine, despite the low loads utilized. Could Bingham and Withers state whether mild scuffing may have obtained in their tests with oil No. 1 in the four-ball machine?

As regards the lack of correlation between scuffing performance in the IAE spur-gear machine and results of high-torque testing in hypoid axles (*cf* Towle's Table IV), the following remarks may, it is hoped, clarify the issue a little.

Whereas under high-speed conditions scuffing is the most common type of failure in hypoid axles, under high-torque conditions failure due to rippling would appear to be at least as common as, and probably more typical than, that due to scuffing. In the light of present knowledge it may be assumed that both for scuffing and rippling the occurrence of high flash temperatures at the meshing tooth faces is a pre-requisite, although in the latter type of wear these temperatures need perhaps not be so very high. However, the nature of the two wear types concerned seems to be quite different, viz.: scuffing is recognized to be a wear type in which local welding plays the essential part, whereas rippling seems to consist in a tangential flow of the surface material.

It would follow that an oil, or a gear material, which performs well in terms of preventing scuffing is not necessarily satisfactory from the standpoint of rippling. For instance, as far as oils are concerned, it is anti-welding properties that are required for combating scuffing, whereas friction-reducing properties seem to be necessary for combating rippling. Now, the anti-welding properties of oils will, in general not correlate with their friction-reducing properties; this is confirmed by the lack of correlation between the rating of oils in high-speed tests in hypoid axles and their rating in high-torque tests, again in hypoid axles.

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* This correlation has never been published, because the Mathis hypoid gear was not considered sufficiently representative of the more common, *i.e.*, American types of hypoid gears.

The conclusion is, that there is no sense in blaming (as is still too often done) laboratory EP testers or spur-gear rigs, if their results do not correlate with hypoid gears in so far as the aim is a correlation with scuffing and rippling simultaneously. On the contrary, it is considered gratifying that as far as scuffing is concerned there is a reasonable correlation between, on the one hand, the IAE spur-gear machine, and even one or two of the presently available laboratory EP testers, and on the other hand, hypoid gears (high-speed conditions). Admittedly, the problem of testing rippling performance by using non-hypoids, such as spur gears, has so far remained unsolved; as far as the discusser is aware, laboratory rippling testers using test specimens other than gears have hitherto not even been developed.

R. TOURRET: I should like to discuss one or two points concerning the detailed design of the self-aligning disk machine described by Watson. In Fig 3 in his paper there is a side and plan view of the machine which may perhaps be represented more simply by Fig 11, in which the outlines of the gear and disk boxes are omitted for clarity.

Care has been taken in the design to ensure that the stub-shaft carrying the smaller disk is quite free to move towards the other disk and to alter its angle relative to the other disk (Fig 12), so that the smaller disk may take up any position relative to the larger disk and is in effect self-aligning under the influence of load.

Watson mentions that in a smaller version of the machine the self-aligning was found unsatisfactory. Could this be due to the Oldham's coupling placed on the end of the stub shaft, which might be expected to restrict the movement of that end of the stub shaft? We have a similar rig, but we have not experienced any self-aligning troubles.* This is probably because our coupling has been deliberately maintained with an adequate amount of clearance in it. It might, however, be better engineering practice to move the gear-box away from the disk-box and to insert an extra shaft connected by two universal joints and a sliding member (Fig 13), so that the stub shaft on which the small disk is carried would be completely free to move.

Another point concerns the position of the driving gear. We have moved it † from the original position (Fig 11) to the other side of the gear-box (Fig 13). This facilitates removal of the disks from the disk-box by permitting the ready removal of the stub shafts through a cover in the side of the disk-box. In practice, a pair of disks can be removed from the Thornton disk-wear machine in less than 10 minutes.

Finally, Watson shows the weight hanging directly from the loading arm. We have interposed a spring between the weight and the carrier (Fig 2 in the paper by Evans and Tourret and Fig 13) so that in the event of

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* It was deemed advisable to increase the self-aligning couple (see Fig 4 of paper by Evans and Tourret, but this was because of evidence of edge contact on *both* edges of the disks, which is unlikely therefore to have been caused by restricted movement of the stub shaft. Without three-land modification to a condition comparable to Watson's test, in which full-width contact disks are used, no self-aligning troubles have been experienced.

† A pulley is used instead of a gear on the Thornton disk-wear machine, which is driven by V-ropes.

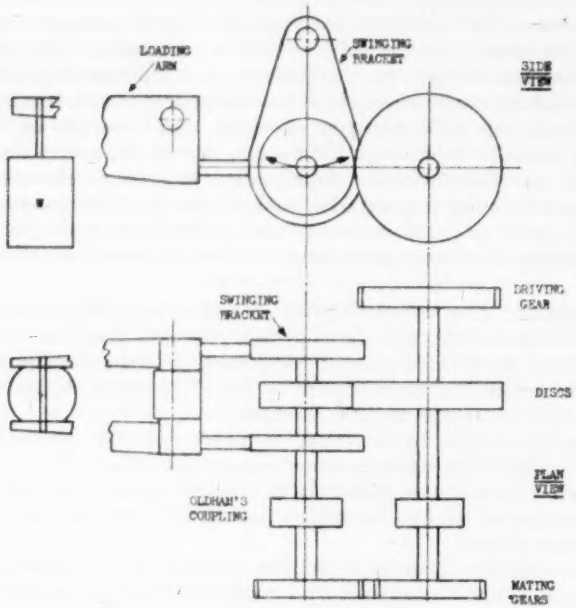


FIG 11

SKETCH OF ORIGINAL LAY-OUT OF DISK MACHINE

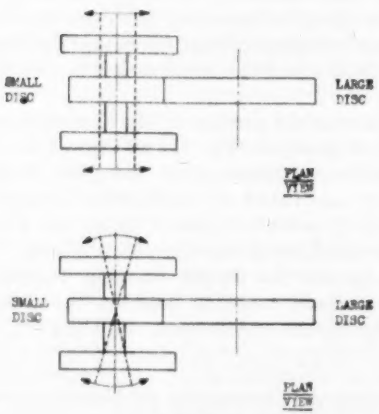


FIG 12

SKETCH OF FREEDOM OF MOVEMENT NECESSARY FOR THE STUB SHAFT TO BE SELF-ALIGNING UNDER LOAD

any vibration, little, if any, shock loading will be transmitted to the disks. The spring was chosen so that its natural frequency did not coincide with any multiple of the vibration frequency.

DR A. CAMERON: In reference to Greenwood and Morton's paper it is clear that the use of a gear to test a lubricant for gearing is correct, pro-

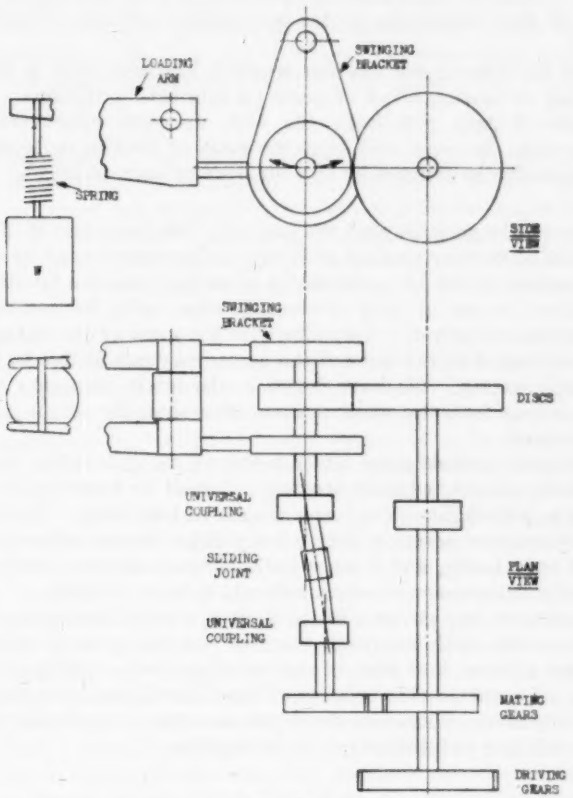


FIG 13

SKETCH OF SUGGESTED LAY-OUT OF DISK MACHINE

viding the test gear is of the same sort as the actual gear. It is, however, becoming increasingly clear that tip relief is of great importance for scuffing. In marine gears the tip relief is of the order of $1 - 4 + 10^{-3}$ inches, the IAE gears have between 2 and $6 + 10^{-4}$ inches relief. Hence the use of the IAE machine to test oils for marine gears is not so obviously correct as might be thought at first. It is for this reason that the use of disks can be defended. They show the load that can be carried under the correct conditions of material, sliding speed, etc., with perfect oil-film

formation, *i.e.*, what gears should do if the tip relief is so adjusted that the oil film is formed with no disturbance from edge contact.

Until the question of tip relief is settled I think that for marine gears the question of the right form of test machine is still very debatable.

J. L. GROFF: I should like to suggest that the ballistic viscometer of Professor F. Charron could be used successfully in investigations of the rheology of gear lubricants so far as sudden increases of pressure are concerned.

I should also like to ask whether research has been done in the field of the shearing or tearing effect of gears on lubricating-oil films. I suggest that blends of light petroleum oils with viscosity improvers, such as acryloids, could be used, and that the ratio of broken molecules to unbroken molecules be referred to as a measure of such an effect.

A. FOGG: In connexion with the paper by Bingham and Withers, I am very interested in their method of trying to determine wear by measuring the iron content of the oil, particularly as we have made a similar attempt to determine the rate of wear of bearings when using lubricating oil containing various abrasives. I wonder whether some of the change in iron content, attributed to the wear of the gears, may not be due to iron from, say, the axle casing. We have found it absolutely necessary to remove any trace of iron from the whole system other than the actual job which is being examined.

Another point in their paper which worries me a little is that they talk of wear without seizure, without scuffing. I shall be interested to know if they have any thoughts on the mechanism of that wear. In the case of gears in automotive practice, they usually either do not wear at all or else they scuff very badly, and I am a little hazy about this conception of a steady and continuous wear on an axle which is not scuffing.

Towle has certainly put in a lot of work of a very interesting character. But in connexion with his paper there is just one point of policy which disturbs me a little, and that is the rather slavish copying of American technique. I mention this because of the difficult and, perhaps, unsatisfactory position which has now developed as a result of a similar copying of technique relating to lubricating oils for engines.

D. I. BADDELEY: It is unfair to say that we are slavishly following United States practice, and I should hate to think that any such imputation, even if correct, were directed to any particular company. Pressure for the adoption of engine tests has been, to some extent anyway, of a military character, and the use in the initial stages at any rate, of test methods and procedures which have some background of experience has been considered necessary.

My point of view, as a member of the staff of the War Office, is rather different from that of most speakers. I was delighted to hear Fogg remark that he did not think the search for a fundamental property associated with the requirements for gears was a forlorn hope. In an organization as large as a Service Department widely varying requirements for

lubricants exist, even in the field of hypoid rear axles. What is really required is a background of fundamental knowledge of all the properties which are required for the successful lubrication of gears of the hypoid type. This should lead to the derivation of a formula or parameter against which lubricant performance can be assessed.

That is a long-term project, and in the meantime we are very grateful to see the progress of work on test rigs. Of particular interest is work designed to yield laboratory-size apparatus which will closely approach the back-axle rig in conditions and results, thus making the work cheaper and yielding quicker results. But there are other test rigs, and indeed it would be a disaster if any one line suggested by these papers should be pursued to the exclusion of others.

C. S. WINDEBANK: I should like to make a few comments as a member of the Standardization Committee of the Institute. I should like to recall the basic purpose of this symposium, which is to gather opinions from those engaged in the mechanical engineering and lubrication industries which would help the standardizing body of the Institute to decide on an approach to the question of standardizing a test method, or methods, for gear lubricants.

Having listened to this discussion, I feel that we would be advised to stop splitting hairs, to ignore the fine distinctions between lubricants which lead one test method to give a rather different result from another, and to concern ourselves instead with major distinctions between lubricants. From the standardizing viewpoint I think we should do better to settle on a test method in the near future and get it standardized in spite of its shortcomings, rather than to continue the confusion which arises out of the existence of so many test methods of equal status. I do not suggest that these many different test methods should not be investigated further, or that they will not always have a place in research laboratories. I do suggest that from the point of view of standardization we should be making more progress for the industry if we choose a test and stick to it until something else is found which is generally acknowledged to be superior.

If we agree that we are getting to this stage, it seems that the first decision to make is whether to use a method which involves test gears, or a machine which tests, or purports to test, some more fundamental property. I have a slight personal preference for a gear machine. This is because I feel that however well founded other test methods may be, we shall not be prepared to accept them as final criteria of the lubricating properties of an oil when we come to putting the oil into an expensive piece of mechanical equipment. We shall always look first for evidence of actual performance in gear lubrication. We shall, in fact, still want a gear-machine test to supplement our other test data.

Apart from the above, I should like to add to the previous comments regarding a tendency to be "slavishly following" United States techniques. I do not see anything wrong in this. It seems to me that if a particular American test does the job adequately there can be no point in wasting time and money in developing another test to supplement it. In adopting it elsewhere there can, in fact, be a lot of advantage in the automatic international standardization which results.

DR C. B. DAVIES: Before the discussion closes I should like to mention worm gears, and would be grateful if Wilford could give some idea as to whether the hypoid axle is perhaps not the better solution to the rear drive of passenger-service vehicles. I cannot help feeling that if we use bronze on steel, as one has to in worm gears, due as Tuplin has shown to the particularly unfavourable slide/roll conditions, we are definitely going to run into problems due to the relatively low yield value of the bronze. In that connexion, is it possible to take advantage of what is done in the application of bearing alloys? In (say) a steel-backed copper–lead bearing we have the advantage of the low yield value of the copper–lead in boundary sliding when the shaft starts up, and hydrodynamic lubrication does not occur; but we also have the steel backing reinforcing that layer of low yield value. Could we not conceive of something similar in the application of a steel-on-bronze gear system, where we should in effect be using a plated gear? In Mansion's paper there were some extremely interesting results on plating, and I feel that that subject could well be developed further.

W. J. DREW: One thing which has come home to me very forcibly is that, having worked on a diversity of problems concerning lubrication, I think the one factor on which we must make a decision is, what is the weak link in the particular design? Is failure due to scuffing, is it due to wear, or is there some other factor, as may be indicated by ball bearings, some load distribution or a lowering of density and pressure? I am thinking now in terms of joints where we get oscillatory motion, where perhaps the problem is one of oxidational wear, which may show another value of lubrication. I think there is a danger in concentrating effort on one machine. We have to decide first on the weak link in our particular problem of investigation, and I think the analytical method is the only one. We have to find what values in oils are good for certain conditions.

REPLIES TO DISCUSSION

A. TOWLE: Since writing my paper a considerable amount of work has been carried out in the development of the high-speed test procedure. The tentative schedule given in the printed paper has been found to be unnecessarily severe, and a schedule has been developed which gives complete correlation with the American Mil–L–2105 high-speed test procedure, and is based on speed cycles between 35 and 55 m.p.h. Under these new test conditions an oil which fails in 5 cycles on the American procedure also fails in 5 cycles on the British procedure, similarly a border-line oil which is satisfactory after 10 cycles and shows failure after 25 cycles gives identical results in both cases, while a pass oil which is satisfactory after both 10 and 25 cycles on the Mil–L–2105 test shows the same characteristics on our own.

I believe that both Baddeley and Windebank have fully covered Fogg's criticism in connexion with the copying of American procedure, and we ourselves feel that under the circumstances in which the U.K. finds itself there was in this case no alternative, but we feel that the very fact that we have been able to use British components and still satisfy the American Army Ordnance is somewhat of an achievement.

The answer to Barwell's inquiry, regarding the possibility of phosphate treatment being used as an alternative to the so-called hypoid-type lubricants is that to avoid trouble during production of large quantities of commercially produced hypoid gears it is necessary to have both the phosphate treatment and to run on a hypoid-type lubricant. The phosphate treatment does materially help the gear during the running-in process.

A surprising feature of both the high-torque and the high-speed tests which we ourselves did not anticipate before commencing the series is that so far complete agreement has been shown between three tests carried out on each individual oil, and so far not a single test has been rejected as disagreeing with the other two of a series.

I should like to draw attention to the type of failure shown in Figs 10 and 11, in which the pinion has failed by rippling. This is a type of failure which does not appear to have been referred to anywhere else in this Symposium, except in the written contribution by Blok. I would agree with this contributor that the two types of failure, *i.e.*, scuffing at high speed, where local welding plays an important part, and rippling under low-speed, high-torque conditions due to tangential flow of the surface material are of completely different character. It is interesting to note that tests carried out subsequent to the publication of the paper appear to indicate good correlation between the results of the full-scale high-speed, low-torque tests on the hypoid axle and the results obtained on the same oils on the IAE machine running at 4000 r.p.m.

I would like to pay a tribute both to the help given by the staff of the MIRA Proving Ground and to those in the industry whose foresight enabled such a useful testing ground to be available to the motor industry.

As has been indicated to some extent in my paper, the whole of the experience of my firm over many years indicates that it is quite impossible to test hypoid oils on other than full-scale hypoid gears. We cannot therefore agree with the statement by Greenwood and Morton that the SAE and Timken machines are useful for testing hypoid lubricants.

The tests on EP lubricants referred to in Watson's paper (see his Fig 9) are particularly interesting, but they leave doubt as to their relation to conditions in service. I have carried out numerous tests on oils drained from hypoid rear axles at various mileages between 500 and 10,000, and these oils have then for convenience been subjected to tests on the IAE 3¼-inch gear rig to see how their EP properties compare with those shown by the new lubricant. Under these conditions there is, as measured by this rig, some falling off in EP properties, but the falling off over the whole 10,000 miles is not too significant, being something of the order of 20 per cent. I presume that Watson's tests were carried out in succession on new disks, and I wonder what the influence of using new disks is on the test results. By this I mean that in service an oil may have EP properties equivalent to a certain figure, and during running it is conceivable that the oil itself loses a certain amount of these properties, but at the same time it surface conditions the gears themselves so that the effective combined load-carrying capacity of the oil plus the gears is constant, in other words what the oil loses the gears may be gaining. Assuming, that it is possible for conditioning of the teeth to take place with certain additives, then the loss in capacity with running time shown in Watson's curves is not

nearly so significant as would at first sight be anticipated. I should be interested also to learn of a possible explanation for the comparatively large change in load-carrying capacity with viscosity of the test oil shown by the IAE machine as compared with the small change with viscosity shown by the disk machine.

With regard to the question asked by Davies regarding substituting hypoid axles for worm-driven axles, I am informed by one commercial-vehicle manufacturer that the reason for the popularity of the worm gear in the U.K. is the comparative ease with which retooling can be carried out when it is found necessary to change the gear ratio to suit different export-market requirements.

Styles and Wilford very significantly remark that the oil industry does not appear to have given the same attention to lubricants for worm-driven axles as it has to lubricants for hypoid gears and other heavy-duty mechanisms. Is the reason for this the fact that it is more difficult to carry out laboratory tests on worm gears than on hypoid gears, due to the comparatively large size of the service-type worm-driven axles, perhaps combined with the fact that people who have investigated in the laboratory worm gears have found that their results do not correlate with practical service experience? My firm is interested in pursuing this subject, and any advice on the setting up of a rig to test worm gears in the laboratory would be appreciated. It has, however, been suggested that the pitting troubles associated with worm-driven rear axles arise from the irregular nature of the torque transmitted by the axle, and therefore cannot be reproduced satisfactorily in the laboratory.

J. R. HUGHES: I regret that there has been so little discussion on what I consider the most important aspect of gear lubricant testing, namely the search for some property of a gear lubricant which is independent of the test method or application but which indicates the potentialities of a material as a lubricant. For present-day requirements it is no doubt advisable to choose a small number of machines covering the various fields of application, but this is necessarily an *ad hoc* measure, and must eventually be replaced by a more logical approach to the problem. Possibly the subject should be left to workers studying the fundamentals of gear lubrication, but nevertheless it is of great practical importance, and it is to be hoped that workers in the more practical fields will not neglect it. I should like to appeal to all users and manufacturers of gears to make available any examples they have of field data in order that research workers will have as much practical data as possible to use as checks on their laboratory findings.

J. G. WITHERS: I would first like to correct an impression which Fogg may wrongly have given in his report, that the tests we have used compete in any way with those of Towle. Our tests measure one aspect of lubricating oil quality in axles, and Towle's tests measure two others. All three of them are important in the evaluation of a lubricating oil. We claim to have established correlation between wear in axles and a simple laboratory test technique.

Unfortunately, from the film strength point of view, as indicated by freedom from high- and low-speed scuffing, there does not seem to be any

laboratory test which gives a satisfactory answer, and until one such test or series of tests has been developed I am afraid we shall have to continue to rely on road tests or axle rig tests.

I would thank Sears for having taken the trouble to analyse our data, which undoubtedly has increased the value of the experiments. It is a pity that it happens to be oil I, of moderate E.P. value, which is the " odd man out " in the family of oils. It makes me wonder whether the correlation between the laboratory tests and road tests holds only for oils of a similar class, namely, lubricants containing hypoid additives. Tests were made on the four-ball machine using base oils without additives, and they showed higher rates of wear than the hypoid-additive oils, and I wonder if the same increased wear will also be experienced on the road. To prove this, road tests are planned on an oil containing no additive, in a car which it is hoped will not give scuffing trouble with such an oil.

As Fogg has suggested, the iron we get on analysis of the oil comes from all the parts that wear. We believe that we get satisfactory and repeatable results because of the choice of an appropriate settling time, which allows the large particles of iron, which are clearly not the result of ordinary wear but are chippings from teeth, to settle out so that they are not taken into account in the final analysis. Prior to the iron content determinations, the samples were mixed for ½ hour, and then allowed to stand overnight (16 hours).

The mechanism of wear without scuffing is a highly controversial matter; theoretically we should get either no wear at all or heavy scuffing; but the conditions in an axle are not ideal, and I think that the steady slow wear that we get in axles and, for that matter, also in engines, is the result of minute scuffing resulting from the local breakdown of the oil film because of surface irregularities or the presence of foreign particles.

I do not think the wear of axles results in many failures, but the probable significance of wear in practice is the early onset of noise from the axle, which is definitely a cause of adverse comment from the user.

We have done a certain amount of work on the four-ball machine with oils of different viscosities, and over the range SAE 10 to 140 with oils containing hypoid additives and the base oils of similar crude source there was no difference in the rate of wear.

In reply to Blok, the four-ball machine wear scars for oil No. 1 were very similar in appearance to those obtained for the hypoid oils. In all cases wear of a smooth form was given, and no sign of metal pick-up or scuffing was observed. As I have mentioned previously, a further road test is planned using an oil containing no additive; this work should show whether the lack of correlation is peculiar to oil No. 1 or whether it is present with other oils not of the hypoid class.

R. D. B. Stone: I have very little to add to my paper, but I do agree with Hopkins that to produce gears to the accuracy called for with profile tolerances of 0·0002 inch, is an extremely difficult matter. Perhaps within that small tolerance differences may have a bigger effect on the oil rating tests than is generally assumed.

With regard to shaving, I support Hopkins again in the view that if test specimens of very much lower hardness were acceptable, gears produced

from a master shaving cutter should have a very high order of repeatability.

In the first half of the symposium Finch suggested that surfaces for gears should be as smooth as possible. I rather differ from that point of view, and I have been made aware of any number of cases where the coarser surface finish to which I have referred in my paper has been without any detriment at all to the functioning of the gears.

R. W. MORTON : Regarding Sears' remarks, and as already pointed out in our paper, we fully appreciate that the data presented do not refer exclusively either to repeatability or reproducibility, as they were obtained on two different machines by a number of operators, although a large proportion were carried out by one operator on one machine. In addition, they were spaced out over a period of about three years, during which a trend was observed towards lower variability. We do not agree that the repeatability bears no relation to the " precision," as, if the repeatability is good, oils can always be rated in the same order; if, however, differences between machines are large and systematic over ranges of failure loads, perhaps another laboratory might rate them in a different order.

We do not, however, see why there should be any such differences, and this appears to be confirmed by the fact that Mansion's results agree well with those in Fig 1 of our paper, and that Lane and Hughes found that the failure loads obtained at 4000 r.p.m. were 63 per cent of those at 2000 r.p.m., compared with 67 per cent on our machines. Moreover, as stated in our paper we have found no significant differences between our two machines, but have found that the quality of the gears used and of the operators employed are the major factors. If, therefore, satisfactory gears and competent operators are employed and the machines are properly maintained, different laboratories should obtain the same repeatability and should rate different oils in the same order, even if the level of failure load obtained varies slightly between different laboratories. This latter could be checked using the same reference oils in each laboratory. We believe these factors account for the differences between our results and those of the Mechanical Tests of Lubricants Panel, although they are not brought out in either report.

This gear effect is well illustrated by Sears' comment that the totals given for the first two lines of Table III in the preprint contain results which show standard deviations (about 13·5 lb) comparable with those obtained in the Panel co-operative work. These results, which should not have been included in the totals, and have now been omitted, were in fact obtained on the same batches of gears as used by the Panel members, and at the same period (1947–48), and would therefore be expected to differ from our subsequent results on gears of more closely controlled quality.

While commenting on the difference of " precision " reported in our paper and in that of the Mechanical Tests of Lubricants Panel, we would like to add that we analysed the failure loads obtained on 122 pairs of gears on which we had tested the same lubricant on both sides of a particular gear pair, and could find no evidence whatsoever that the standard deviation increased with the average failure load, although this was an essential feature of the findings of the Mechanical Tests of Lubricants Panel.

Referring now to the criticism of Table II, we agree that the results may at first sight appear to be misleading. We should like to say in amplification that we considered our further analysis was justified because the ratio of " side-to-side " to " all sides " data was proportionally the same as used throughout the subsequent tables (1 : 3). It is admittedly a rough-and-ready criterion. We should, however, add that a subsequent rigid analysis of variance restricted to only those gear pairs which were tested on both sides showed no difference between sides of a gear pair and " all sides," and this is certainly a more potent justification of our methods. Sears has made unfavourable comments on the use of a reference oil, but we consider that there are undoubtedly circumstances in which one is indispensable, for example in the calibration of gear batches; unless the batches are so calibrated, Sears' arguments must, we consider, fall to the ground.

As regards our method of presenting the data, we feel that this must remain a matter of opinion. It would, of course, have been much easier to have given bare conclusions, but we considered that this would be unsatisfactory to the majority of readers; on the other hand, full details of all results obtained, and statistical analyses of these, would, we feel, have been unsuitable and even confusing to many readers, as well as being inappropriate in this type of paper. We therefore indicated the methods of analysis used, as this seemed to be the fairest compromise.

McEwen commented on the dynamic loading which appears to be characteristic of the results given in Fig 5. We had noticed this effect and are now waiting to see if it is confirmed by further results on the high-speed rig. At present insufficient data are available to allow a stress calculation to be made.

H. J. Watson: With regard to the design details of the slow-speed, self-aligning disk machine mentioned by Tourret there is possibly a little restraint imposed by the use of Oldham couplings. When one or both disks are not casehardened the effect of such restraint is not apparent in the results, and a probable explanation is that the small amount of compensation needed is provided during bedding-in of the disks.

Tourret's question about our abandonment of the split swinging frame on the 3-inch machine is not easy to answer. There seems no fundamental reason why the smaller machine should not be self-aligning, but although when trouble was experienced numerous modifications were tried, they were not consistently successful. Perhaps restraint by the Oldham coupling had something to do with the difficulties, although small effective disk face-width may also have had some influence. It was found, however, that the solid swinging frame more easily produced consistent results, and we therefore decided to use it instead of pursuing the split-frame design.

The high-speed 6-inch machine used for testing turbine gear lubricants, and particularly when both disks are casehardened, includes long carden shafts between the gearbox and disk machine. Largely because of balancing difficulties a rigidly coupled small diameter flexible shaft drives the 4-inch disk and the shaft driving the 8-inch disk is coupled through universal joints. Similar modifications are also being successfully applied to one of the slower-running machines. A practical difficulty arising out of this arrangement is that the insertion of each new pair of disks necessitates re-lining up

the machine, but no effect from restraint has been detected in the results.

The use of a spring to support the load was also mentioned by Tourret. We have used, and in fact, generally do use springs for this purpose, having first ensured that resonance difficulties were unlikely to be encountered, but the advantages derived from isolating the load by a spring are by no means marked. The essential point seems to be in ensuring by accuracy of disks and the machine generally that very little oscillation of the load arm occurs.

I was very interested to note that one or two speakers commented on the effect of surface smoothness. Actually we have been careful to control that because it appears that if the surfaces are given a certain degree of initial roughness the materials will bed down satisfactorily. On the other hand, if the surfaces are made with too smooth a finish to start with it is extremely difficult, and indeed almost impossible, to obtain contact evenly spread across the face-width of the disks before scuffing occurs; that is one of the difficulties with casehardened materials.

The surfaces of through-hardened disks tend to deform slightly under load, probably by a small amount of plastic flow and thus permit a full face contact, but the effect of support at the edges of the track by adjacent material has not yet been fully explored. Casehardened disks running together do not permanently deform, and we have evidence to show that bedding-in is effected by abrasive wear or really, by intermittent scuffing occurring over a very short interval of time, as the load increases. Each small scuff reduces the load concentration, and usually the surfaces quickly recover although the load is continuously increasing. When recovery does not take place the oil film is regarded as having broken down. The same sequence of events appears to occur during the running-in of hypoid gears.

Towle made some comments about the correlation between disk tests and performance of hypoid oils in actual axles. A certain amount of work has been done running hypoid axles under load and comparing results with those obtained from disks. There may be something in his suggestion that a succession of new disks may hasten the loss of capacity, since in the tests new pairs are put into the machine one after another and run until they scuff, using the same charge of oil. In the axle, however, the first pair of gears scuffed severely after 30 hours' running under various loads and speeds simulating road conditions. The same charge of oil topped up with new oil at each change of gears was used, and three subsequent pairs of gears failed by scuffing in progressively shorter periods, until in the last case, after a total of about 50 hours of running with the oil, scuffing was produced at quite a light load, suggesting that the additive had been used up. Disk machine tests on samples of the oil indicated that initially EP properties were present, but none was found in the sample taken from the axle after the tests had been run. That is a point which needs consideration.

In vehicle back axles it seems likely that for successful operation of hypoid gears the oil charge must retain its EP properties during the time necessary for the gears to run-in, after which high load-carrying capacity is of smaller importance.

As to the diagram which McEwen mentioned, Fig 10, it deals with the effect of sliding velocity on the scuffing load of steel disks, and his calcula-

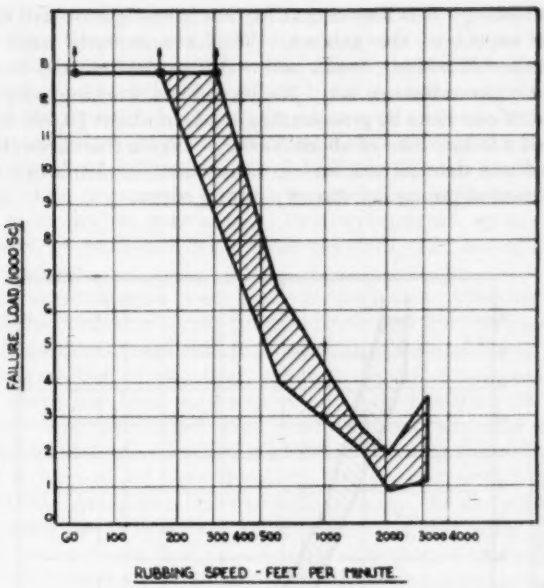


FIG 14

SCUFFING TESTS WITH OM 88 OIL AND EN.36 CASEHARDENED STEEL DISKS

Slide/roll ratio—large disk, −1·0; small disk, +0·5.

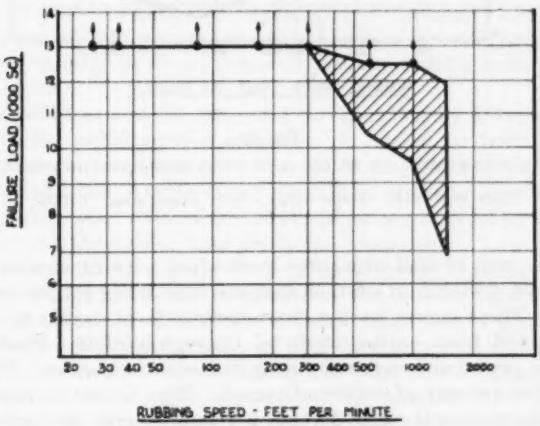


FIG 15

SCUFFING TESTS WITH OM 88 OIL AND EN. CASEHARDENED STEEL DISKS

Slide/roll ratio—large disk, −0·2; small disk, +0·16.

tions are interesting; it is hoped that further investigation will throw more light on this aspect of the subject. We have recently used the curve shown for slide/roll ratios +0·833 and −5·0 to determine a lower breakdown point for the reference oil. We have been working with a rubbing speed in most of our tests to give scuffing loads of about 10,000 to 12,000 S_c and we needed a failure load of about 5000 S_c. From the curve the required rubbing speed was determined, and in subsequent confirmatory tests most of the experimental points lay directly on the curve.

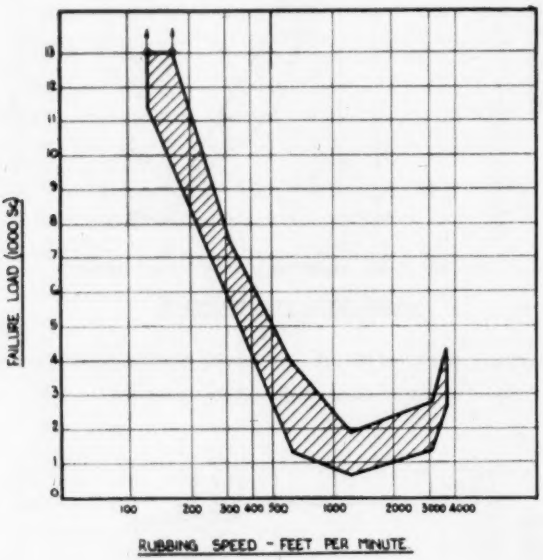


FIG 16

SCUFFING TESTS WITH OM 88 OIL AND EN. CASEHARDENED STEEL DISKS

Slide/roll ratio—large disk, −0·5; small disk, +0·33.

Figs 14, 15, and 16 deal with some work which is being carried out under the auspices of AVGRA in a 6-inch disk machine using En.36 casehardened steel disks. These curves have a characteristic form similar to that of the curves obtained from earlier work on through-hardened steels (such as Fig 10 in the paper) although exhibiting rather more scatter. The hatched areas show the amount of scatter obtained. Figs 14 and 15 were produced with different slide/roll ratios but show much general similarity. Fig 16 relates to work which is still going on, but it shows the results to date; it has a third slide/roll ratio. There has not yet been time to analyse these completely, but it has been established that they conform to the equation S_cV = a constant except at the highest speeds, where there is increase of S_c with speed, and agree with results obtained from actual gears.

A. T. WILFORD: In his summary Fogg stated that we had been carrying out tests with low-viscosity oils containing various types of oxidation inhibitors. The reference to "low-viscosity" oils is perhaps a little misleading. It is true that the base oil employed in the tests and subsequently standardized is of lower viscosity than was the oil of 205 to 235 cs at 140° F (850 to 950 sec Redwood) previously used in bus rear axles. But the lower viscosity oil (135 to 155 cs at 140° F—550 to 625 sec Redwood) is of a viscosity grading commonly used in worm-driven axles and was already employed in trolleybus rear axles. Our experiments, at the stage so far reached, have no analogies with those involving the use of low-viscosity oils in bus engines.

Towle has emphasized a point made in the paper by Styles and myself; it is that the oil industry seems to have neglected the lubrication of worm gears and has concentrated rather on hypoid and spiral bevel gears. It is not an exaggeration to say that apart from the development we have described, there has been no progress in the lubrication of worm gears since I have been associated with road vehicles, which is a long time. I am interested to learn that Towle's firm is pursuing this subject.

All that we have as yet been able to do is to prevent or to minimize something which was giving us a lot of trouble, namely, the excessive thickening of the oil during use. There can be no doubt that this thickening led to an increase in power losses and presumably contributed to the wear of the gears; it also caused a certain amount of difficulty in garage maintenance as well as in the reconditioning of the axles at overhaul. But although we have reduced this trouble, we have done nothing whatever to reduce the wear problem.

In this connexion I am not very happy about the method described by Bingham and Withers for determining wear. They say they have neglected that portion of the iron which is due to flaking. I have had little or no experience with hypoid gears, but in the case of worn gears, I am quite sure that the amount of metal removed through flaking is far in excess of that due to wear.

I think Towle has already answered the question by Davies concerning hypoid axles for public-service vehicles. It has to be remembered that although operators of public-service vehicles may design, and sometimes build their own bodies, it is the usual practice for these bodies to be mounted on commercial chassis. The design of the latter is governed by the demands of the export market rather than the home consumer.

Davies referred to the possibility of employing a steel worm wheel coated with lead-bronze as an alternative to the conventional bronze worm wheel. Apart from the difficulties in fabricating such a gear I am very doubtful whether the thin coating of lead–bronze would survive the conditions which lead to such heavy flaking and pitting as is now encountered.

Temby referred to the oil-change periods recommended for rear axles of passenger cars. So far as public-service vehicles are concerned, oil-change periods are related to general maintenance procedure; they have to fit in with everything else, and an operator must be prepared to accept some degree of compromise. In London Transport, for example, the change period for engine oil may be set at 6000 miles or 7500 miles, but when this has been done, the rear-axle oil will have to be changed at some multiple of

the mileage chosen for engine-oil changes. It has always been my impression that there is no scientific basis for the recommendations applying to private cars. These recommendations come from either the maker or the oil supplier, neither of whom has the requisite user experience. The periods advocated are more frequent than those usually adopted by operators of commercial and public-service vehicles, though the greater annual mileage which these vehicles perform is a factor which should perhaps not be forgotten.

THE CHAIRMAN: This brings us to the end of our proceedings. I have found this meeting to be extremely enjoyable and instructive, and all of us who are interested in this range of subjects have obtained a good deal of food for thought.

Before we leave I think it will be your wish that we should thank the authors of the fifteen papers, and also Dr Clayton and Mr Fogg for the part they have played in to-day's proceedings. Will you join with me in thanking them in the usual way?

(The thanks of the meeting were heartily accorded, and the meeting closed.)

ABSTRACTS

	PAGE
OILFIELD EXPLORATION AND EXPLOITATION	
Geology	461 A
Geophysics and Geochemical Prospecting	463 A
Drilling	463 A
Production	466 A
Oilfield Development	468 A
TRANSPORT AND STORAGE	470 A
REFINERY OPERATIONS	
Refineries and Auxiliary Refinery Plant	474 A
Distillation	475 A
Absorption and Adsorption	476 A
Solvent Extraction and Dewaxing	477 A
Cracking	478 A
Hydrogenation	481 A
Polymerization	482 A
Alkylation	483 A
Isomerization	483 A
Chemical and Physical Refining	484 A
Special Processes	485 A
Metering and Control	489 A
PRODUCTS	
Chemistry and Physics	491 A
Analysis and Testing	498 A
Crude Oil	502 A
Gas	503 A
Engine Fuels	504 A
Gas Oil and Fuel Oil	504 A
Lubricants	505 A
Bitumen, Asphalt, and Tar	508 A
Special Hydrocarbon Products	509 A
Derived Chemical Products	510 A
Coal, Shale, and Peat	512 A
Miscellaneous Products	513 A
CORROSION	514 A
ENGINES AND AUTOMOTIVE EQUIPMENT	515 A
SAFETY PRECAUTIONS	517 A
MISCELLANEOUS	518 A
ADDITIONS TO THE LIBRARY	523 A

AUTHOR INDEX

The numbers refer to Abstract Numbers

Ackerman, P., 2334
Adams, C. E., 2332, 2345
Agnew, R. J., 2492
Alexanian, C., 2417
American Petroleum Institute, 2540
Anderson, H. C., 2486
Arnold, H. R., 2339
Arnold, R. C., 2486
Aronofsky, J. S., 2248
Arundale, E., 2342
Asser, E., 2477
Atkinson, R. G., 2465
Atteridg, P. T., 232

Backlund, P. S., 2354
Baer, M. E., 2492
Bailey, M. F., 2535
Bailey, W. A., Jr., 2353
Bailly, F. H., 2228
Ballande, H., 2527
Ballweber, E. G., 2345
Banes, F. W., 2342, 2486
Bannerot, R. A., 2353
Barford, W. B., 2486
Baricau, R. B., 2354
Barnard-Smith, D. G., 2395
Barnett, H. C., 2444
Barrick, P. L., 2487
Bartleson, J. D., 2470
Barton, J. A., 2533
Bassinger, R., 2244
Beach, F. K., 2452
Beam, J., 2332
Becker, R., 2336
Beddow, S. B., 2486
Befahy, E., 2281
Benoit, J., 2399
Benson, H. E., 2364
Berg, C., 2311
Bergman, D. J., 2375
Berriman, J. A., 2310
Bestougeff, M., 2388, 2401
Beychok, M. R., 2369
Bielstein, W. J., 2241
Birch, S. F., 2485
Bland, R. E., 2330
Blott, J. F. T., 2437
Blum, H. A., 2249
Bodig, R. D., 2513
Boldrini, M., 2526
Bolt, J. A., 2354
Bond, R., 2354
Boord, C. E., 2386
Bottom, V. R., 2244
Boucheny, J., 2402
Bowden, E. P., 2414
Bowen, B. E. V., 2486
Bradfield, S. A., 2451
Bradford, D. W. 2385
Bradford, E. B., 2490
Bragg, C. G., 2361
Brattain, R. R., 2423
Breese, J. L., 2459
Breuer, F. W., 2486
Brewer, A. F., 2468
Brook, J. H. T., 2398
Brooks, C. H., 2354
Broome, D. C., 2435
Brown, H. C., 2486
Brown, R. A., 2423
Brownley, H., 2454
Brunner, C. T., 2543
Burch, S. W., 2459
Burney, D. E., 2389
Burroughs, L. C., 2285
Butcosk, R. A., 2470
Buzon, J., 2417

Cade, G. N., 2372
Caesar, C. H., 2329
Caesar, P. D., 2354
Campbell, A. S., 2418
Campioni, E. C., 2352
Cannon, M. R., 2305
Carnahan, J. E., 2339
Carney, B. R., 2450
Carpenter, C. Le Roy 2372
Chambers, J., 2300
Chesler, S., 2298
Chmelevsky, A., 2429
Clarke, J. T., 2486
Cluer, A., 2480
Cobley, R. C., 2483
Collins, R. E., 2246
Concannon, L. E., 2492
Cordia, J. P., 2352
Cornell, P. W., 2332
Cornu, A., 2434
Cotton, E., 2332
Courteaud, J., 2268
Crandall, G. S., 2537
Cranmer, W. W., 2495
Cromeans, J. S., 2372
Crowell, J. H., 2364
Croxton, F. C., 2531
Cummings, J. D., 2245
Cushman, W. W., 2508

Da Fano, E., 2492
Daimler, K., 2477
Dalquist, M. S., 2479
Dalton, S. D., 2327
Darmois, R., 2410
Dart, J. C., 2325, 2372
Dawson, E. J., 2315
De Benedictis, A., 2492
De Haas van Dorsser, A. H., 2301
De la Chappelle, M., 2374
De Meeus, E., 2542
De Saint-Leger, B., 2446
Deanesly, R. M., 2371
Deely, C., 2243
Demester, J., 2365
Deschenes, A. P. H., 2268
Deutsch, C. G., 2524
Deveaux-Charbonnell, J., 2536
Devlin, P. A., 2486
Donovan, B. J., 2486
Doty, A. E., 2479
Dougherty, P. F., 2354
Dugleux, P., 2416
Dumas, H., 2229
Dupas, R., 2446, 2449
Duspira, F., 2479

Eardley, E. J., 2231
Eckel, J. B., 2241
Edwards, R. H., 2435
Egloff, G., 2341
Emmett, P. H., 2362
Evans, E. M., 2491
Evans, T. W., 2492
Evering, B. L., 2319

Farquhar, J. C., 2381
Farragher, W. F., 2324
Farrar, G. L., 2296, 2377
Farris, R. F., 2244
Faulk, R. W., 2532
Favre, E. J., 2402
Fearson, R. E., 2235
Feller, N. N., 2344
Fetterly, L. C., 2353
Fidler, F. A., 2395
Field, J. H., 2364
Fitzgerald, W. P., 2486
Fleming, H. W., 2372
Folda, B., 2256
Fombona, G. T., 2403
Fowler, R. D., 2486
Fox, H. W., 2412
France, R. M., 2344
Franck, H., 2477
Frankel, P. H., 2267
Franta, W. A., 2342
Free, G., 2309, 2460
Freling, E., 2416
French, A., 2478
Freund, M., 2314

Gable, C. M., 2353
Garner, P. J., 2486
Gates, J. I., 2237
Gebhart, A. L., 2486
Gee, W. P., 2318
Geiser, N., 2471
Gelderman, C., 2288
Geller, J., 2477
Gerhold, C. G., 2332
Gibbons, E. F., 2541
Gilkeson, P. W., 2236
Gilmont, R., 2394
Giraud, A., 2365, 2439, 2525
Gishler, P. E., 2474
Gislon, A., 2373
Glassmire, W. F., 2499
Gleason, A. H., 2342
Göhre, O., 2309
Golovanov, N. V., 2330
Good, G. M., 2326
Gorshkoff, A. S., 2459
Grable, D. B., 2244
Graff, R. A., 2368
Grandjean, H. H., 2433
Granier de Lilliac, R., 2525
Graves, B. S., 2510
Gray, G. R., 2236
Green, J. E., 2275
Greensfelder, B. S., 2326
Groen, E., 2528
Gross, H. H., 2318
Grosskinsky, O., 2309
Grunberg, L., 2390
Guillemin, A., 2365–6
Gwynn, M. H., 2539

Haanebrink, F. C., 2269
Haase, R., 2303
Hall, C. C., 2363
Hammar, C. G. B., 2338, 2426
Hammerich, T., 2455
Hammond, T. C., 2492
Hamontre, H. C., 2254
Hanford, W. E., 2492
Hannum, J. A., 2457
Hansen, H., 2488
Hanson, O. M., 2354
Hanson, R. A., 2289
Hariow, E. V., 2464
Harrison, W. J., 2517
Hartough, H. D., 2354
Hays, L. A., 2354
Hayward, J. T., 2245
Heaps, S. N., 2234
Heider, R. L., 2486
Hellin, M., 2439
Henderson, G. M., 2400
Hendrickson, R. L., 2244
Hickman, K. C. D., 2309
Hirsch, J. H., 2332
Hodges, L. P., 2372
Hodgson, G. W., 2474
Holmes, H. R., 2286
Hoog, H., 2351
Howell, W. C., 2457
Howlett, J., 2486
Hyams, H., 2284, 2286
Hyman, J., 2479
Hyson, A. M., 2372

Imhausen, K-H., 2373
Ingram, H. L., 2511
Ipatieff, V. N., 2339, 2345

Jackson, J. G., 2244
Jacob, M., 2281
Jacobsen, E. W., 2283
Janssen, C., 2292
Jasion, L. Z., 2479
Jenner, E. J., 2486
Jesser, B. W., 2298
Jewell, J. W., 2428
Johnson, A. B., 2245
Johnson, J. E., 2479
Johnson, P. B., 2486
Jones, H. H., 2368
Jones, L. C., 2422
Jones, P. C., 2481
Jost, W., 2303

Kalinuskkin, M. P., 2280
Karsten, W., 2529
Kastrop, J. E., 2252
Kaye, H., 2483
Kazanskii, B. A., 2387
Kelley, K., 2256
Kemp, J. D., 2346
Kerkhof, W. P., 2545
Kerkhoven, R. E., 2475
Keunecke, E., 2373
Killins, C. R., 2250
Kilpatrick, M. O., 2372
Kimberlin, C. N., 2332
King, L. F., 2470
Kinney, P. T., 2250
Klempt, W., 2309
Knaus, J. A., 2350
Knowles, R. S., 2520
Knutson, A. T., 2470
Kölbel, H., 2334
Kolling, H., 2333
Konrad, W. H., 2312
Kószegi, R., 2430
Krach, L., 2374
Krause, J. H., 2313
Kükenthal, H., 2491
Kummer, J. T., 2362
Kuss, T. M., 2244

Langlois, G. E., 2340, 2347
Lanham, B. E., 2535
Lefevre, P., 2278
Leffler, F. W., 2332
Leftwich, R. F., 2459
Leibowitz, J., 2535
Levine, P., 2419
Levy, N., 2486
Levy, W. J., 2514
Lidov, R. E., 2479
Lien, A. P., 2319
Lipkin, M.R., 2425
Llewellyn, W. E., 2492
Low, J. W., 2330
Lukasiewicz, S. J., 2354
Lukina, M. Yu., 2387
Luten, D. B., 2492

McCauley, D. A., 2319
McCoy, P. E., 2476
McDermott, J. P., 2470
Mack, C., 2492
McKay, J. F., 2479
McKinley, J. B., 2339
Mahan, R. L., 2242
Mantel, W., 2488
Mapstone, G. E., 2407–9
Marot, G., 2442
Marsehner, R. F., 2389
Martin, A., 2525
Martin, C. C., 2425
Martorano, J., 2403
Marx, A., 2477
Massey, L., 2406
Matchen, B., 2474
Matheson, G. L., 2479
Matsas, E., 2440–1
Matthews, J. B., 2398
Matuszak, A. H., 2470
Mavity, J. M., 2532
Mawer, F. C., 2486
Mayer, A. W. J., 2530
Meade, R. H., 2259
Meadors, V. G., 2244
Mellett, D. S., 2383
Melpolder, F. W., 2423
Merriam, E. S., 2256
Mertzweiller, J. K., 2486
Meyer, H. R., 2508
Mikeska, L. A., 2470, 2479
Millar, R. W., 2353
Miller, C. A., 2459
Mills, G. A., 2332
Minken, J. W., 2292
Moehrle, E., 2477
Moen, R., 2479
Monicard, R., 2229
Morell, Le G., 2470
Morlock, H. E., 2459
Morrell, J. C., 2342
Morway, A. J., 2470
Mosteller, J. C., 2491
Mottern, H. O., 2486
Münster, W., 2373
Mussell, D. B., 2479
Muth, G., 2420
Myhill, A. R., 2453

Návarre, R., 2523
Nelson, J. F., 2486
Nelson, W. L., 2287, 2403
Neppe, S. L., 2436
Neyhaus, M., 2358
Neznayko, M., 2236
Nielsen, R. F., 2250, 2378
Nieuwenhuis, W. E., 2482
Nissan, A. H., 2390
Nocturne, J., 2534
Noeske, H., 2373
Noll, H. D., 2330
Noll, P. E., 2277
Nonnenmacher, H., 2420
Norris, H. D., 2470
Nottes, G., 2408

O'Brien, V. J., Jr., 2304
Odell, W. W., 2489
Oettinger, W., 2420
O'Gara, H. K., 2532
Oliveira da Silva, J., 2515
Olsen, J. L., 2312
Oppenheim, A. K., 2415
O'Shields, R. L., 2253
Ospina-Racines, E., 2516
Othmer, D. F., 2394
Oxford, W. F., 2293

Palmer, J. S., 2332
Panchenkov, G. M., 2330
Parker, J., 2376
Parr, J. O., 2234
Patch, G. W., 2289
Paterson, E. V., 2461
Patton, R. L., 2380
Payne, L. L., 2240
Pearson, J. M., 2244
Pelipetz, M. G., 2337
Pellettere, J. A., 2380
Peters, M. S., 2305
Peterson, L. W., 2299
Peterson, W. S., 2474
Pfender, M., 2463
Pfenning, G. E., 2237
Phillips, C., 2499
Pidgeon, D. G., 2481
Pier, M., 2335
Pierce, J. A., 2332
Pierson, E., 2486
Pigott, R. J. S., 2383
Pines, H., 2339, 2345
Pitzer, E. W., 2372
Plank, N., 2282
Plant, J., 2484
Platt, A. M., 2377
Poell, H., 2317
Pohl, H., 2302
Polizzotto, P. L., 2354
Pompeo, D. J., 2376
Popkin, A. H., 2470
Porter, Brown, B., 2537
Pribuitkova, N. A., 2397
Pringle, J. W., 2487
Proell, W. A., 2345
Prokop, C. L., 2238
Puddington, J. E., 2469
Pullar, H. B., 2476

Quesson, M., 2399
Quiquerez, J., 2373
Quist, H. A., 2289

Rampino, L. D., 2396
Ratte, H., 2477
Read, D., 2331
Reamer, H. H., 2247
Redlick, O., 2353
Reeves, E. J., 2321, 2391
Reichl, E. H., 2332
Reman, G. H., 2316, 2351
Rennie, J., 2363
Resek, J. V., 2458
Resen, F. L., 2343, 2355, 2367, 2521
Robert, L., 2402, 2417
Roegiers, M., 2370
Rogers, D. T., 2457
Roman, W., 2431
Rose, A., 2304
Rosenmund, K. W., 2453
Ross, J., 2486
Rossini, F. D., 2384, 2427
Rössler, R., 2420
Rubinshtein, A. M., 2397
Russell, R. D., 2244
Ryland, L. B., 2396

Sage, B. H., 2247
Sass, F., 2503
Schall, J. W., 2325
Schestopal, R., 2333
Scheurer, A., 2473
Schlaffer, W. G., 2396
Schläpfer, P., 2430
Schmalfeld, P., 2420
Schneider, K. W., 2404
Schneider, W. R., 2499
Schrader, G., 2491
Schultze, H-U., 2477
Schwall, H., 2513
Schwarzenbek, E. F., 2328, 2350
Schweitzer, P. H., 2503
Scott, F. S., 2289
Segel, E., 2479
Selund, R. B., 2354
Sery, P., 2374
Shagrin, E. G., 2411
Shellshear, W. A., 2270
Sherwood, P. W., 2323

Shinonda, H., 2244
Shmidl, H. J., 2486
Shokal, E. C., 2486
Siebert, W., 2447
Sigwalt, R., 2429
Silverman, D., 2244
Simmers, C. D., 2476
Simon, R. F., 2234
Simpson, T. P., 2327
Sipple, H. E., 2470
Sirianni, A. F., 2469
Skelton, W. E., 2318
Slade, E. B., 2513
Sleightholme, J. J., 2492
Slobod, R. L., 2249
Slyngstad, C. E., 2328, 2350
Smirnov, L., 2233
Smith, A. E., 2353
Smith, C. W., 2257
Smith, H. M., 2539
Smith, H. W., 2294
Smith, P. V., 2470
Smith, S. S., 2376
Smith, W. R., 2499
Smithuysen, W. C. B., 2351
Smittenberg, J., 2393
Snel, R., 2467
Sommer, N. B., 2358
Spann, R. E., 2263
Sparks, W. J., 2342
Spencer, R. K., 2483
Sproule, L. W., 2470
Squire, E. S., 2481
Squires, P., 2256
Stage, H., 2392
Stahmer, A. M., 2262
Standard Oil Development Co., 2348, 2373
Stansfield, R., 2445
Staton, J. C., 2244
Sterman, S., 2470
Stickland, A. E., 2346
Stillinger, R. G., 2510
Stine, H. M., 2332
Stokoe, E., 2266
Storch, H. H., 2364
Stormont, D. H., 2239
Stratford, C. W., 2354
Stratford R. K., 2329
Stross, F. H., 2469
Struck, K-H., 2309
Sullivan, F. W., 2371
Swaminathan, W. S., 2272
Swaney, M. W., 2479
Sweetman, W. G., 2244

Tamele, M. V., 2396
Taylor, D. M., 2270
Thayer, J. M., 2235
Theobald, C. W., 2492
Thomas, R. M., 2342
Thompson, B. J., 2450
Thompson, L. L., 2244
Thornton, D. P., 2307, 2360
Tishler, M., 2486
Tom, T. B., 2354
Tramm, H., 2333
Trigg, H. S., 2470
Tullar, I. V., 2276
Tullos, F. N., 2244
Turner, O. M., 2379

Uhl, W. C., 2297

Vámos, A., 2314
Van Amerongen, G. J., 2492
Van der Waarden, M., 2413
Van Ebbenhorst Tengbergen, H. J., 2382
Van Emden, E., 2466
Van Ess, P. R., 2470
Van Nes, K., 2428
Van Pelt, A. T., 2509
Van Soest, L. L. W., 2291
Van Vleet, J. G., 2289
Van Wijk, W. R., 2301
Vasey, J., 2290
Vasserberg, V. E., 2397
Vernet, Ch., 2432
Verver, C. G., 2437
Vesterdal, H. G., 2312
Voge, H. H., 2326
Vold, M. J., 2405
Vold, R. D., 2405

Wadsworth, F. T., 2486
Waldrip, H. E, 2496
Walkey, J. E., 2340
Wallace, B. P., 2476
Walsh, B. R., 2283
Wasserman, D., 2470
Watson, C. W., 2372
Watts, E. V., 2256
Weber, G. H., 2538
Weber, W. F., 2470
Weghofer, H., 2373
Weikart, J., 2332
Weir, T. P., 2422
Weismann, G. H., 2313
Weiss, W. J., 2244
Weller, R., 2337
Weinert, P. C., 2341
Weschky, L., 2373
Wesp, A., 2438
West, J. P., 2332
Whetstone, R. R., 2492
White, P. C., 2371
White, P. T., 2395
White, R. V., 2470
Whitney, J. E. S., 2491
Whitney, W. B., 2308
Widmer, M., 2544
Wigton, H. F., 2487
Winkler, de L. E., 2486, 2492
Withers, G. L., 2322
Withers, J. G., 2462
Wolf, M. A., 2479
Wollner, P., 2459
Woolfolk, R. M., 2274
Works, G. A., 2497
Worthing, R. C., 2425
Wrightson, J. M., 2320

Yahnke, R. L., 2313
Young, H. D., 2443
Young, W. S., 2423
Yowell, H. L., 2479

Zentmyer, D. T., 2486
Zimmerschied, W. J., 2486
Zisman, W. A., 2411–12
Zublin, J. A., 2344
Zuiderweg, F. J., 2306

Oilfield Exploration and Exploitation

Geology

2228. Thermal differential curves reflect subsurface geology. F. H. Bailly. *World Oil*, May 1952, **134** (6), 77.—Ditch samples of clays at close depth intervals have been examined by the differential thermal analysis technique, in which curves are obtained representing records of the heat changes occurring in the samples when heated at a constant rate. For any formation, differential curves obtained from a series of cuttings represent the assemblage or suite of minerals present over the chosen interval.

The clay samples contained no apparent markers, but thermal analysis showed varying ratios of siderite and clay minerals. C. A. F.

2229. Radioactivity of sedimentary rocks, crude oil and subsurface waters. R. Monicard and H. Dumas. *Rev. Inst. franç. Pétrole*, Apr. 1952, **7** (4), 95–102.—The publications on radioactivity in sedimentary rocks, crude oil, and subsurface waters are reviewed. The radioactivity measurements are made in an ionization chamber (useful for α-particles) or by a Geiger–Müller counter (γ-rays can be measured; some forms of counter will give β-particles only; others will detect α-particles). The activity may be due to potassium, or the uranium and thorium series. Sediments have appreciable radioactivity. For sandstones the range is $0{\cdot}19 \times 10^{-12}$ gm Ra/gm to $1{\cdot}42 \times 10^{-12}$ gm/gm. The mean value for limestones is about $0{\cdot}5 \times 10^{-12}$ gm Ra/gm; for shales the mean is about $1{\cdot}08 \times 10^{-12}$ gm Ra/gm. Heavy minerals containing uranium or thorium, potassium-bearing minerals and possibly colloidal radioactive materials are the source of the radioactivity in sediments. The last seems the most important.

In crude oils the average radon content is $0{\cdot}19 \times 10^{-12}$ curie/gm, and the radium content $0{\cdot}018 \times 10^{-12}$ gm/gm. The average Rn/Ra ratio is about ten times the equilibrium ratio. It is believed that the oil picks up radon during migration.

Oilfield waters are believed to have higher than usual radioactivity. Radioactive materials in shales could act on oil for a relatively short time, while the feebler activity

in the reservoir will act for a longer time. Both may affect the oil or organic matter. There are difficulties in the hypothesis that radioactivity transforms organic matter to oil, but they are not insurmountable. G. D. H.

2230. Examination of well cuttings. J. W. Low. *Quart. Col. School of Mines*, Oct. 1951, **46** (4), 1–48.—The types of well cuttings, their examination using the low power binocular microscope, and the recording of the sample data are described in detail.

Well cuttings are of two types: rotary and cable tool. Rotary cuttings are normally flaky in shape with sizes ranging from $\frac{1}{4}$ to $\frac{1}{8}$ inches, depending on the character of the rock, the sharpness and type of bit, and its rate of penetration and loading. Cavings may be as large as 2 inches. Adjustments to sample depths must be made for lag in circulation of cuttings to surface.

Cable tool cuttings are generally finer than those from rotary holes, and cavings may be difficult to distinguish; there is no lag between cutting and sampling.

The quality of well samples varies considerably, and it is important for the geologist to distinguish between representative cuttings and cavings.

In the preparation of samples for examination, coarse and fine materials can be separated by "dry panning," and steel shavings from the bit can be removed by a magnet. All samples must be properly washed or winnowed in front of a fan to remove clay and dust particles before examination under the microscope. Accuracy of sample description is of prime importance in the examination of well samples, and a standard method of plotting the strip log should be used.

It is recommended that coarse clastics be plotted in yellow, fine clastics in their natural colour, carbonate rocks in blue, and evaporites in black-line symbols. The properties of sediments that should be recorded and various test methods for mineralogical determinations, including hardness and stain tests, are described, together with the precautions to be taken in interpreting the samples and methods of plotting logs. The use of other types of logs, such as drilling-time logs, to provide additional data is recommended.

A list of materials useful in the preparation, examination, and recording of running samples is included, and examples of strip logs are given. C. A. F.

2231. Utah's oil outlook brightens. E. J. Eardley. *World Oil*, May 1952, **134** (6), 73.—Present daily oil production in Utah is 3000 brl from four fields in the Uintah Basin: Ashley Valley, producing from the Weber sand; and the Roosevelt, Red Wash, and Duchesne fields, producing from the Green River. There are gas fields at Clay Basin, and at Boundary Buttes, which is undeveloped; gas has been discovered in the Clear Creek well in Carbon County which flowed 8 million cu. ft/day.

Oil production in the state has been developed over the past four years, although surface indications have been long known; these included solid hydrocarbon dykes. Future potential is assessed in relation to four criteria: the volume of sedimentary rocks, evidences of oil and gas at the surface, unconformities, and wedge belts of porosity.

The three most recently discovered fields are in buried structures, detected by seismic methods. Closure is small, and accumulations may not be due to anticlinal control. Several favourable seismic structures have been tested without success.

Future location of commercial fields in Utah will require careful integration of geological and geophysical methods. C. A. F.

2232. Carter drills well in Anadarko Basin. Anon. *Petrol. Engr*, Apr. 1952, **24** (4), B112.—Emby Kaye 1, Beaver County, Oklahoma, flowed 128 brl of clean oil in 3 hr with gas estimated at 1 million cu. ft/day. Pay is limestone at 5833 to 5849 ft. C. A. F.

2233. Oil in Russia. Pt 3. L. Smirnov. *World Oil*, May 1952, **134** (6), 264.—There is active exploration of the cis-Alpine trough which extends along the Alpine system of the Carpathian Mountains, the Crimea, and the Caucasus. Structures are complex Tertiary folds complicated by salt tectonics; structures presently being explored are those along the outer rim of the trough and Palæozoic structures near the edge of the Russian platform.

Within the cis-Alpine trough there are separate basins separated by transverse

elevations. One of these, the Azov–Black Sea trough is separated from the cis-Carpathian trough by the North Crimea transverse elevation where Tertiary and possibly Mesozoic oil-bearing rocks have been found in the Melitopol area. In the Kerch and Tamar basins numerous oil-bearing diapiric structures have been found, but no fields have been developed. Structures on the southern slope of the Azov–Black Sea trough in the Maikop area are richly oil bearing, and the area has substantial reserves. C. A. F.

Geophysics and Geochemical Prospecting

2234. Patents. U.S.P. 2,586,731 (11.3.49; 19.2.52). R. F. Simon and S. N. Heaps, assrs to Socony-Vacuum Oil Co. Inc. Seismic exploring system.

U.S.P. 2,586,706 (12.1.49; 19.2.52). J. O. Parr, assr to O. S. Petty. Seismic surveying. J. M. S.

2235. Patents. U.S.P. 2,583,904 (10.7.48; 29.1.52). J. M. Thayer and R. E. Fearon, assrs to Well Survey Inc. Neutron well-logging method. R. C. R.

Drilling

2236. Solidification of lime-treated muds at high temperatures. G. R. Gray, M. Neznayko, and P. W. Gilkeson. *World Oil*, Mar. 1952, **134** (4), 101.—The use of lime-treated muds is widespread in the drilling of deep holes, but the increased hole temps have given rise to a thickening of the mud. Although not restricted to lime-treated muds, it was shown that these do show pronounced thickening properties, with resultant inconvenience in drilling operations: high pump pressures, inaccurate logging due to the failure of the electrode to reach bottom, seizure of packers, inefficiency of perforating operations. The loss of water to the formation was unlikely, and it was subsequently shown that there was no water loss; thickened muds showed the same concentration as initially.

In addition to the standard tests, chemical analyses were made on the muds, and in view of the inadequacy of the gel tests, a two-bladed penetrometer was constructed.

The effect of pressure on the thickening of the mud was so small as to be within the experimental error of apparatus used. Time and temp both contributed to thickening. Changes in the alkalinity suggested an interaction between the bases and other components of the mud. Samples of mud were dispatched to other laboratories for X-ray analysis. A mud was made up of a lime bentonite slurry in order to confirm the trend shown in the field muds. The use of selected thinners is recommended. Experimental data and procedures; references. A. J. H.

2237. New oil base emulsion mud hailed as vast improvement. J. I. Gates and G. E. Pfenning. *Oil Gas J.*, 12.5.52, **51** (1), 166.—A new oil-base emulsion mud has been developed by Shell Oil Co. of California. Called Shell Resin Soap Mud, it is stable at temp up to 250° to 275° F, and is suitable for densities up to 125 lb/cu. ft. Although designed primarily for drilling the 8000 to 13,000 ft D6 and D7 oil zones in Ventura Avenue field, it has proved equally satisfactory for shallower drilling. J. C. M. T.

2238. Radial filtration of drilling mud. C. L. Prokop. *J. Petrol. Tech.*, Jan. 1952, **4** (1), *AIMME Tech. Paper No.* 3246, 5–10.—Conditions in an API wall-building tester differ from well conditions in the occurrence of flow and other respects. Flow carries away particles which might otherwise enter a filter cake. Rate of potential deposition will be controlled by the filtration characteristics, pressure differential, temp, and the current cake thickness. Resistance to erosion of the cakes may differ considerably.

The experimental filter cell consisted of a hollow sand cyl cemented by phenol-formaldehyde resin or a hollow cyl of sintered brass. In most tests the pressure differential was 350 p.s.i. and the temp about 110° F. The cake thickness was measured by a gauge for flowing conditions. In some cases a cake was formed under non-circulating conditions, and then flow was allowed to erode this cake.

The muds ranged 2 to 85 cp viscosity, and 7 to 148 cc API filtration.

For flow it was found generally that the higher the filtration rate the thicker the

equilibrium filter cake and the higher the eroding velocity needed to stop further cake formation. The filtration rate of a mud had little or no effect on the cake thickness when cakes formed under static conditions were subjected to several hours erosion by mud flow. All filter cakes so formed were very difficult to erode by mud flow.

The data indicate that a water loss of about 20 cc API will give a thin cake under continuous circulation, but when circulation in a well stops a thick cake may be formed which will be difficult to erode.

Mud visc in itself had little effect on cake erosion, but turbulence was more effective than streamline flow in removing mud cake. For turbulent flow the rate of erosion was proportional to the square of the circulation velocity. At normal rates of flow only about $\frac{1}{32}$ inch/hr was removed.

Filter cakes formed under continuous circulation decreased in permeability throughout the experiment after a constant thickness has been reached. Muds with very high water loss deposited thick cakes despite very high eroding velocities. G. D. H.

2239. Lost circulation cure. D. H. Stormont. *Oil Gas J.*, 19.5.52, **51** (2), 85.—Another successful trial of air-drilling has occurred, at Shell's South Mountain field, Ventura. The first 1000 ft of hole encountered highly fissured volcanic rocks which took mud as fast as it could be supplied. Air drilling, using 4180 cu. ft. of air/min at 100 p.s.i., enabled this 1000-ft section to be drilled in one day at half the cost of cable-tool drilling. Current practice is to drill up to six slant holes from an "island," drilling the first 1000 ft of all before replacing the compressor by mud pumps and completing the holes normally. J. C. M. T.

2240. Effect of circulating media and nozzle design on rock bit performance. L. L. Payne. *J. Petrol. Tech.*, Jan. 1952, **4** (1), 9–13.—Tests showed increased penetration rate, greater footage per bit, and a reduction in cost per foot when air was circulated instead of water. Seismograph shot holes have been successfully drilled with air circulation. This is an advantage where water is scarce or the temp low. Excellent results have been reported with gas circulation when drilling gas wells where fluids damaged the formation. Rates of penetration were found to fall with increase in mud visc, but this can be offset by increasing the wt on the bit or increased rate of circulation. However, the results varied with the rock. Back pressure reduced the rate of penetration. The incorporation of oil in the mud (emulsion) increased bit life, drilling rate and footage per bit, and saved bits, trips, and rotating time in most cases. Oil base and oil emulsion muds increase bit bearing life. Oil base mud adversely affected penetration rate and footage per bit.

In general, high velocity jets directed on bottom improve rock bit performance as compared with conventional jets directed on the cutters. G. D. H.

2241. Nozzle design and its effect on drilling rate and pump operation. Pt II. J. R. Eckel and W. J. Bielstein. *World Oil*, Mar. 1952, **134** (4), 115. (*See also* Abs. No. 1799.)—The velocity distribution in jet streams was determined with the use of traversing pitot tubes in a specially constructed high-pressure test chamber, and it was shown that there is a rapid dissipation of the stream energy beyond the jet outlet. The rate of penetration is affected by the circulation rate and the nozzle fluid velocity; the product of these two factors being proportional to the impact force; measurement of this was by a weighing platform.

The conclusions from the tests indicate that more efficient nozzles would lead to an appreciable reduction in the required pumping h.p.; or a higher rate of drilling could be obtained with the available rig h.p. The location of the nozzle of the drag-bit closer to the cutting edge has definitely contributed to longer bit life, according to field results. Extensive data in graphs. References. A. J. H.

2242. "K" Monel non-magnetic drill collars for oil well surveying. R. I. Mahan. *World Oil*, Mar. 1952, **134** (4), 130. (*Pacific Coast District, Divn of Production, API.*)—A review of the history and development of the K-Monel drill collar. It provides a highly accurate means of obtaining survey records, without the influence of a magnetic drill collar. The method cuts down on round trip time and, in view of the fact that the survey instrument is kept in the collar, no danger of losing it arises. The Monel has been selected for its overall durable qualities, after consideration of beryllium–

copper and certain stainless steels; its principal drawback is that it wears more rapidly than conventional drill collars. References. A. J. H.

2243. Diamond coring instruction. Pt II. C. Deely. *World Oil*, Mar. 1952, **134** (4), 124. (*See also* Abs. No. 1788.)—In general, it is recommended that the rotary table and pumps should be operated from independent motors; in this way the correct volume delivery of drilling fluid may be ensured. The accurate estimation of the well depth does reduce the danger of running the bit to bottom and so damaging it. A pressure increase of 100 to 150 p.s.i. for water-base muds, and 200 to 250 p.s.i. for oil-emulsion muds is an indication that the bit has reached the true bottom. Sources of unusual pressure fluctuations are given. In conclusion, the accurate interpretation of the manufacturer's instructions will ensure more efficient coring, and depends on the maintenance of rig equipment. (Certain outstanding errata of the preceding article are appended.) A. J. H.

2244. Patents. U.S.P. 2,584,768 (20.7.49; 5.2.52). W. J. Weiss, assr to Texaco Development Corpn. An aqueous drilling fluid contains reaction products formed in aqueous solution from an alkali metal polyphosphate and a water-soluble compound containing copper, silver, mercury or nickel. The alkali metal polyphosphate is used in slight excess so that the reaction products are complex alkali metal heavy metal polyphosphates.

U.S.P. 2,584,930 (Netherlands 10.12.48; 5.2.52). H. Shinonda, assr to Shell Development Co. Drilling fluid for wells contains an aromatic mineral oil, a finely divided weighting material, and from 1 to 20% by wt of the oil of a microcrystalline paraffin wax.

U.S.P. 2,584,978 (13.9.48; 12.2.52). R. Bassinger. A well percussion tool fitted with a skirt and neck, the neck being fixed to the main tubular housing in a position to telescope with the skirt and being designed to close fluid ports in the skirt when the neck and skirt are telescoped.

U.S.P. 2,584,979 (24.9.48; 12.2.52). R. Bassinger. Well percussion tool.

U.S.P. 2,585,207 (11.10.50; 12.2.52). J. A. Zublin. Apparatus for drilling a lateral bore from an existing vertical well bore.

U.S.P. 2,585,378 (1.3.46; 12.2.52). R. F. Farris, assr to Stanolind Oil and Gas Co. Cementing of wells by introducing first a hydraulic cement slurry containing a starchy material and then a slurry of coarsely ground hydraulic cement clinker. The second slurry is introduced under pressure so that it is physically dehydrated when it contacts a permeable formation in the well, resulting in a squeeze pressure.

U.S.P. 2,585,386 (26.6.47; 12.2.52). R. L. Hendrickson, assr to Stanolind Oil and Gas Co. Method of taking core samples of formations being penetrated by a bit comprises flowing a core barrel by direct circulation to a position adjacent the bit, releasably latching the core barrel, cutting and collecting a core while maintaining reverse-circulation drilling and releasing the core barrel containing the sample and flowing it to the surface while continuing the reverse-circulation drilling.

U.S.P. 2,585,412 (29.4.50; 12.2.52). D. Silverman, assr to Stanolind Oil and Gas Co. A method of well productivity logging is described involving locating the position of the interface between a brine phase and a heavier solvent phase in the producing well.

U.S.P. 2,585,701 (28.12.48; 12.2.52). L. L. Thompson. A mud mixer for well drilling mud in which dry material is given a preliminary mixing before being directed to the main mixing chamber.

U.S.P. 2,586,662 (20.8.48; 19.2.52). J. G. Jackson, assr to Eastman Oil Well Survey Co. A directional drilling apparatus designed to permit continuous drilling of a deflected bore in the direction of the guide surface of a deflecting tool to a considerable distance beyond the end of the deflecting tool.

U.S.P. 2,586,745 (26.11.47; 19.2.52). F. N. Tullos, assr to Standard Oil Development Co. Acoustic well logging system.

U.S.P. 2,586,878 (8.5.47; 26.2.52). J. C. Staton, assr to Eastman Oil Well Survey Co. Drilling apparatus.

U.S.P. 2,586,911 (23.3.50; 26.2.52). V. R. Bottom. Specially designed containers for explosives for shooting oil wells. A number of the containers may be lowered into the well and be vertically nested.

U.S.P. 2,586,939 (12.11.46; 26.2.52). D. E. Grable. Cutting tool for deflected drilling.

U.S.P. 2,586,966 (8.8.49; 26.2.52). T. M. Kuss and R. D. Russell. Deep water oil well drilling structure.

U.S.P. 2,587,244 (12.11.46; 26.2.52). W. G. Sweetman, assr to J. J. McCullough and O. J. McCullough. Apparatus for cutting pipes in a well.

U.S.P. 2,587,501 (30.12.49; 26.2.52). V. G. Meadors, assr to Standard Oil Development Co. A drilling fluid comprising an aqueous dispersion of clay containing a polyoxyalkylene derivative of a hexitan ester of a higher fatty acid to increase its viscosity.

U.S.P. 2,587,518 (21.1.49; 26.2.52). J. M. Pearson, assr to Sun Oil Co. Electrical logging method and apparatus. J. M. S.

2245. Patents. U.S.P. 2,583,819 (2.7.48; 29.1.52). J. D. Cummings. A machine for applying protective coating materials to pipes.

U.S.P. 2,583,841 (2.3.48; 29.1.52). J. T. Hayward. Apparatus for measuring rotary well strings and well depths.

U.S.P. 2,584,022 (4.9.47; 29.1.52). A. B. Johnson. Surface pipe bracing and centring means for the base of a well drilling derrick. R. C. R.

Production

2246. Determination of the transverse permeabilities of large core samples from petroleum reservoirs. R. E. Collins. *J. appl. Phys.*, 1952, **23**, 681.—The calculation of the permeability of petroleum reservoir rocks, in the plane parallel to the bedding plane, from measurements of the transverse flow of a gas through large cyl cores is described. The solution is obtained by analogy with the corresponding problem in potential theory, the method of conformal transformations of complex variables being employed. An electrolytic model of the problem is described, and a comparison is given of theoretical and experimental results. L. G. H.

2247. Volumetric behaviour of condensate and gas from a Louisiana field—II. B. H. Sage and H. H. Reamer. *J. Petrol. Tech.*, Jan. 1952, **4** (1), *AIMME Tech. Paper No.* 3233, 11–14.—The formation volume and the relative volume of the liquid phase of mixtures of condensate and gas from five different parts of the field have been determined experimentally on samples taken from surface separators. The studies included gas-condensate ratios as high as 25,000 cu. ft/brl at pressures up to 5000 p.s.i. The tank condensates ranged 53·9° to 63·9° API.

The compositions of the condensate and gas samples are tabulated, and the specific volumes of the mixtures are given. The retrograde dew-point pressure is tabulated for one sample at temperatures ranging 40° to 220° F and pressures of 6000 to 14,000 p.s.i. A nearly linear relationship was found to exist between the formation volume and the gas-condensate ratio under isobaric–isothermal conditions.

The volumetric behaviour of fluids from several fields is compared. G. D. H.

2248. Mobility ratio—its influence on flood patterns during water encroachment. J. S. Aronofsky. *J. Petrol. Tech.*, Jan. 1952, **4** (1), *AIMME Tech. Paper No.* 3221, 15–24.—The results of potentiometric model studies and numerical computations for a line flood are described. The ratio of distance between the rows of injection wells and the spacing of the injection or producing wells was 1·5. Both techniques were used for mobility ratios of 10 and 1, and only the potentiometric method for the mobility ratio of 0·1. The mobility ratio is $\frac{(K/\mu)_w}{(K/\mu)_o}$, where K is the permeability and μ the visc, while the suffixes w and o refer, respectively, to water and oil.

The sweep efficiencies were found to be 61%, 70·8%, and 86·6% for mobility ratios of 10, 1, and 0·1 respectively. Hence allowance must be made for the effects of mobility ratio variations in reservoir analyses.

In the studies it was assumed that all volume elements ahead of the flood interface were characterized by the K/μ value for oil, and all those behind the interface by the K/μ value for water. In each region there was supposed to be one mobile fluid only.

The theory of the method of computation is given. G. D. H.

2249. Method for determining wettability of reservoir rocks. R. L. Slobod and H. A. Blum. *J. Petrol. Tech.*, Jan. 1952, **4** (1), *AIMME Tech. Paper No.* 3245, 1–4.—The wettability of reservoir rocks by oil or water is of interest, particularly in connexion with certain conventional laboratory studies made on core samples. The wettability of a sample is considered to be given by the contact angle for the oil–water–solid system. The contact angles are calculated from the displacement pressure (threshold) observed in a centrifuge, using first oil–water and second air–oil in the same sample. It is assumed that the air–oil and oil–water interfaces occupy similar positions in the porous medium when desaturation of the wetting phase begins; also that the contact angle for the air–oil–solid system, which is close to zero, does not change appreciably even when the contact angle for the oil–water system changes markedly. "Apparent contact angles" for several natural and artificial porous media ranged 31° to 82°. The apparent contact angle for a single sample changed from 33° to 53° in laboratory use.

Cases of oil wetness in reservoir samples are believed to be due to the accumulation of an adsorbed film in which the polar group of a large organic molecule is adsorbed on the surface, leaving the hydrocarbon part of the molecule projecting outwards from the solid. G. D. H.

2250. Capillary pressure and wettability studies on Pennsylvania sands. P. T. Kinney, C. R. Killins, and R. F. Nielsen. *World Oil*, Mar. 1952, **134** (4), 174.—The importance of capillary pressure phenomena in relation to production problems has been recognized for some time. Two particular aspects are discussed in the relation of the wettability of cores to the relative permeability to each phase, and the correlation of various textures of cores by use of the J-function.

The behaviour of the sand depends largely on its history, and an attempt was made therefore to eliminate this effect by approaching the problem from both possible conditions; the cores were extracted and completely saturated in independent tests, with each phase. Capillary pressure curves for the water-into-oil and oil-into-water conditions were then established. It was shown that the Bradford sands showed a preference for oil, while the Venango sands were preferentially water wet. Data have also been obtained from mercury injection tests.

Data are presented graphically. References. A. J. H.

2251. Water floods that failed. Anon. *Oil Gas J.*, 12.5.52, **51** (1), 162.—Case histories of five water flood projects in Mid Continent fields which, for one reason or another, proved unsatisfactory, are presented and discussed. J. C. M. T.

2252. Automatic production controls for pumping and flowing leases. J. E. Kastrop. *World Oil*, Mar. 1952, **134** (4), 153.—A review of the successful operation by automatic control of oil production from 164 producing and flowing wells. Certain limitations are mentioned, in order to assist other operators in assessing their particular difficulties. A. J. H.

2253. Effect of sand-filled perforations on well performance. R. L. O'Shields. *Oil Gas J.*, 19.5.52, **51** (2), 128.—Sand-filled perforations introduce a large pressure drop at the well bore which restricts productivity. Sand-filling does not usually occur when external gravel-packing is employed, but the productivities of wells using inside casing sand filters, which do suffer, can be increased to approach those of outside filters by substantially increasing perforation size and density above the usual four or six ½-inch shots per ft. In competent producers shot penetration is more important than number and size of shot holes. J. C. M. T.

2254. Locating abandoned wells. H. C. Hamontre. *World Oil*, Mar. 1952, **134** (4), 184.—Abandoned wells have been the cause of loss of general field efficiency when giving access to thief zones. Of particular importance is the plugging of such wells before commencing water injection projects. Generally the programme consists in collecting all available information relating to the oil wells in a particular lease, and surveying the property generally. Once the locality of the well is established, use may be made of mine detectors, pipe finders, and other devices. Unfortunately many wells have had the surface casing removed, and these give rise to much more complicated procedures. A. J. H.

2255. Secondary recovery by CO_2. Anon. *Petroleum*, July 1952, **15** (7), 188–9.—Some methods at present in use or under test for the recovery of oil left in subsurface formations are outlined. The use of CO_2 which, in laboratory and field tests, has shown notable improvement in recovery is described in more detail, referring principally to the British Patent No. 669,216 of the Oil Recovery Corp. This method entails the injection of CO_2 into an oil-bearing structure in amounts readily soluble in the formation liquids to bring about the desired modifications so that the oil is more readily removed, *i.e.*, its interfacial tension is changed and its capillary attachment and absorption removed. The operating technique and some results comparing the CO_2, methane, and nitrogen methods are also given. R. E. P.

2256. Patents. U.S.P. 2,584,605 (14.4.48; 5.2.52). E. S. Merriam and F. Squires. Oil is recovered from geological formations in which oil and other combustible materials are present in different strata, by igniting the said other combustible materials to provide heat to reduce the visc of the oil and then withdrawing the oil.

U.S.P. 2,584,606 (2.7.48; 5.2.52). E. S. Merriam and F. Squires. Recovery of oil by means of an input well and a venting well. A combustible gaseous mixture is forced into the input well together with water and is ignited to produce gases and steam, which penetrate towards the venting well and reduce the visc of the oil, which is withdrawn from the venting well.

U.S.P. 2,585,522 (8.3.47; 12.2.52). E. V. Watts and B. Folda, assrs to Socony-Vacuum Oil Co. The productivity of oil wells is increased by introducing a minute quantity of a dihydrocarbon silicone into the space within the well surrounding the tubing.

U.S.P. 2,587,333 (15.5.50; 26.2.52). K. Kelley. Gas–liquid separating device for oil wells. J. M. S.

Oilfield Development

2257. Exploration 20% ahead of 1951 record. C. W. Smith. *World Oil*, May 1952, **134** (6), 86.—20% more exploratory wells were completed in the U.S.A. in the first quarter of 1952 than in the same period of 1951. Of a total of 2840 wells, 491, or 19·8%, were completed as producers.

Tables show the results of exploratory drilling in the U.S.A. in March 1952, and first three months, 1952–51, by districts, and a summary of the results of exploratory drilling. C. A. F.

2258. Completions reach first quarter peak. Anon. *World Oil*, May 1952, **134** (6), 48.—4001 wells were completed in the U.S.A. in Mar. 1952, compared with 3412 in the same month of 1951. Cumulative completions for the first three months of the year were 11,087, 12·1% more than for the same period of 1951. Texas, Oklahoma, Kansas, and California are the major drilling areas.

A table shows well completions in the U.S.A. during Mar. 1952 and first three months 1952. C. A. F.

2259. Naval reserves important. R. H. Meade. *World Oil*, May 1952, **134** (6), 66.—Petroleum reserves of the U.S. Navy are centred in four areas, these are: Elk Hills, California; Buena Vista Hills, California; Teapot Dome, Wyoming; and northern Alaska.

At Elk Hills, 46,000 acres are controlled, containing approx 653 million brl of recover-

able oil. Production is at present limited to that required for testing and protection against water encroachment and drainage.

At Buena Vista Hills, 30,000 acres are controlled, and operations are unitized.

The Teapot Dome area has been shut down for many years. Oil shows have been found during recent testing of deep horizons, and several more test wells are planned.

In northern Alaska the reserves cover 37,000 sq. miles, and exploration in recent years has discovered one field containing recoverable oil reserves estimated at 30 to 100 million brl. Natural gas has also been found in several areas, and there are many untested prospects.

The U.S. Navy also controls two large areas of oil shale deposits near Rifle, Colorado, and in Utah. C. A. F.

2260. Petroleum progress in South America—1. Peru. Anon. *Petroleum*, July 1952, **15** (7), 186–7.—Describes exploration activities and refinery development in Peru. Current operating capacity by the International Petroleum Co. Ltd. is 27,000 b.d. R. E. P.

2261. Petroleum progress in South America—2. Chile. Anon. *Petroleum*, July 1952, **15** (7), 187.—Describes recent exploration, refinery construction, and gives production figures. Average oil figures for 1950 were: density, 0·8063° to 44° API; sulphur 0·08%; water and impurities 0·1%. R. E. P.

2262. More German crude. A. M. Stahmer. *World Oil*, May 1952, **134** (6), 245.—German production in 1951 was 9,656,000 brl, 22% more than in the previous year. Geophysical surveys, mainly seismic, were carried out, chiefly in northwestern Germany, the Upper Rhine Valley, and the Forealps area. Several new structures were found, and oilfields were discovered at Hohne and Hemmelte-West. Three gas fields were found at Frenswegen, Itterbeck, and Rheden; and gas has also been discovered at Wolfskehlen.

At Hohne, south of Eldingen, the wildcat discovery well initially flowed 353 b.d. from Liassic sandstone at 5759 to 5782 ft, and pay was later found in the Rhaetic. The field, which is faulted, produced 21,130 brl in Dec. 1951.

At Hemmelte-West, 15 miles northwest of Quakenbrueck, the wildcat discovery found oil in the Gigas and Kimmeridge at 3998 to 4067 ft.

There were important extensions to the Suderbruch field in 1951, and a third pay was discovered in the Gigas; the main pay is Cornbrash at approx 6560 ft.

At Rheden, near Diepholz, high pressure gas was found in the Bunter sandstone at 5790 ft.

At Frenswegen and Itterbeck, near the Dutch border, gas was found in Zechstein dolomite; and there was further development of the nearby Ruehlermoor–Ruehlertwist field group and the Lingen–Dalum and Georgsdorf fields.

In the Holstein–Hamburg area an offshore well, Helmsand 1, was drilled to test the Rhaetic. Dry porous sands were found, and the well was abandoned at 7550 ft.

The discovery of gas at Wolfskehlen 1, in Darmstadt in southwestern Germany, has stimulated exploration in the Rhine Valley, and a number of tests have been made.

Estimated German reserves at the beginning of 1951 were 194,342,500 brl proven and 74,203,500 brl probable. C. A. F.

2263. New line to hike Indonesia output. R. E. Spann. *World Oil*, May 1952, **134** (6), 248.—Crude output of Indonesia will be increased by approx 40,000 to 200,000 b.d. as a result of the completion of the 12-inch pipeline from the Minas field of central Sumatra to a terminal on the Siak River. The Minas field was discovered in 1944, but it was not developed until 1950. Two fields near Minas, Duri and Sebanga, have been inactive since their discoveries in 1941 and 1940.

At Pungut, 25 miles north of Minas, two wells were completed on a small structure during 1951, and four producers were drilled in the Lirik–Ukui field, which formerly produced from only 1 well at 44 b.d.

In South Sumatra two new fields were found in 1951, at Deras and Abad. At the end of the year Deras was producing 23 b.d. from two flowers, and Abad, 636 b.d. from three flowers.

Crude production in Indonesia in 1951 was 55,309,545 brl, compared with the pre-war peak of 62,087,000 brl. C. A. F.

Transport and Storage

2264. The largest motor tanker. Anon. *Motor Ship*, June 1952, **33** (387), 90.—Plans and photographs are given of the *Berenice*, the largest motor tanker yet constructed and one of the biggest oil-carrying ships in the world with her d.w.c. of 31,640 tons. Total machinery output is 13,500 b.h.p., and mean speed attained at trials, with vessel fully laden, was 15·95 knots. Boiler oil is used in the engines. Cargo pumps, deck machinery, accommodation, electrical installation, machinery, auxiliaries for main engines, steam generating plant, and performance are discussed. U. M.

2265. Oil tanker "World Unity." Anon. *Engineer*, 1952, **193**, 825–6.—This tanker is first of ten ordered from Vickers Armstrong Ltd. on behalf of World Tankers Corporation of Liberia. Main features: 653 ft long overall, 86 ft wide, 31,745 tons deadweight, driven by 12,500-s.h.p. steam turbines, speed 15 knots; crew of fifty-six housed in quarters to latest requirements of Ministry of Transport; steam smothering system in oil cargo tanks and cargo hold, CO_2 smothering system in propelling machinery space and cargo pump rooms; fitted with cargo derricks, radar mast, electrically-driven auxiliaries. A. C.

2266. Tanker turn round—some practical aspects of the discharge of ocean tankers. E. Stokoe. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 171.—The procedures normally adopted for discharging bulk oil cargoes from ocean tankers are described. Other matters discussed include disposition of tanker discharge connections, separation between different grades by valves or blank flanges, permissible hose pressure and movement, use of shore steam, discharge of heated cargoes, and delay before and after discharging operations. D. K.

2267. Short-term and long-term tanker freight rates and the significance of their fluctuations. P. H. Frankel. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 185.—The various methods by which tankers are available for the carriage of petroleum are discussed, *e.g.*, oil company owned vessels, long- and medium-term charters, short-term charters.

The last covers about 5% of total carriage. The operating costs of tankers and long-term charter freight rates are more stable than short-term freight rates. D. K.

2268. Oil ports—new French installations. J. Courteaud and A. P. H. Deschenes. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 145.—The industrial concentration of two groups of refineries one in Provence and one in Basse-Seine has influenced the development of new petroleum ports in Marseille–Lavéra and Le Havre. They supply crude oil to refineries, to which they are linked by pipeline. The operations of a tanker in a port of discharge are discussed, and a study of the minimum time necessary for this purpose is made. Plans of the two ports are included. D. K.

2269. International regulations for the transport of liquid fuels on the inland waterways of Western Europe. F. C. Haanebrink. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 179. (In French).—A preliminary conference in 1933 laid down draft regulations giving rules for the construction and fitting out of tankers and other vessels used for transport of combustible liquids, for transport, and for the handling of liquid fuels. Though the agreement was only concluded in 1939, it has not come into force yet, but the proposed rules have been followed in several countries since their publication. The regulations govern details of the classification of products and of means of transport, the construction and fitting out of vessels specially designed for transport of bulk and packed goods. Instructions are laid down for the handling of liquid fuels. D. K.

2270. Seagoing compressor station. W. A. Shellshear and D. M. Taylor. *World Oil*, Mar. 1952, **134** (4), 205.—Three compressor stations have been designed to compress and process generally, approx 50 million cu. ft. gas daily, which previously were flared off. Water content is cut down from 72 to about 7 lb/million cu. ft., and condensate recovery is from 10 to 20 b.d. The transmission line pressure is 825 p.s.i., after

compression of the gas from the high pressure separators at 325 p.s.i. and low pressure separators at 125 p.s.i.

The barges are submersible, but completely recoverable with eleven ballast tanks. Corrosion is minimized by ballasting with fresh water, and in addition to the protective coatings the portion of the hull exposed to tidal level fluctuations is protected by double plates. Careful design has limited vibration to a very low level.

The barges have given satisfactory service since Oct. 1951. Flow diagrams and photographs. A. J. H.

2271. Centrifugal cargo pumps for tankers. Anon. *Motor Ship*, June 1952, **33** (387), 96.—Increased interest has been shown since the war in the possible advantages of centrifugal pumps on British built ships, because of the steadily increasing size of tankers and the limited berthage for oil discharging. The pumps described and illustrated are: (1) Worthington-Simpson vertical unit, which has an hourly output of 500 tons water at 125 p.s.i., 350 tons oil at 2000 sec Red. I. at 125 p.s.i., and 300 tons spirit at 0·7 sp. gr. at 110 p.s.i. (2) Hayward-Tyler two-stage pumps, which have a range of capacities from 580 to 1080 tons seawater per hr against a discharge pressure of 140 p.s.i. U. M.

2272. The trans-Arabian pipeline "Tapline." V. S. Swaminathan. *Engineer*, 1952, **193**, 556–8 and 611–13.—Tapline is world's biggest oil pipeline system connecting oilfields of eastern Saudi Arabia with Mediterranean shipping terminal at Sidon (Lebanon). Arabian American Oil Co. (Aramco), producing from oilfields at Abqaiq in South-east Saudi Arabia, operate line as far as Quaisumah, 315 miles northwest of Abqaiq. Remaining 754 miles to Sidon operated by Trans-Arabian Pipeline Co. Ownership of both these companies divided between four American oil interests. Bulk of line built in 30-inch and 31-inch pipe, shipped nested from U.S.A. to conserve space. Much other material, *e.g.*, cement, stowed inside 30-inch line during shipment. Line constructed from both ends, completed Sept. 1950. 60% of line is buried, 40% overground; buried pipe protected with asphalt and fibre glass. All pipe made by rolling plates into cyls, longitudinally welding by submerged arc process, and cold hydraulic expansion to exact O.D. Latter process increased yield point to 52,000 p.s.i. min. Among numerous construction problems overcome were the following: (1) unloading facilities for materials at Persian Gulf end, for which 3-mile overhead cableway was erected, connecting mainland with artificial unloading island for ocean ships; (2) road alongside route of pipeline for trucking pipe and other materials, 930-mile highway constructed; (3) water supply to workers, necessitating drilling of fifty-two water wells. Fleet of cars and special trucks exceeded 1500 units. Six pumping stations were constructed at about 180-mile intervals. Each station operates four diesel engine driven centrifugal pumps in series, discharging at final pressure of 840 p.s.i.g. A community of 200 to 300 will eventually be required at each station. An additional booster pump station is under construction which will increase capacity of line by 12,000 b.d.; this station is completely automatic and will operate unattended. Crude oil storage at Sidon includes sixteen tanks each of 180,000 brl, from which tankers are offloaded at 19,000 to 26,000 brl/hr by gravity flow. Capacity of line is 300,000 b.d., total operational stock is 6 million brl. Installation cost was $230 million. A. C.

2273. Steam-heated pipeline moves high-viscosity Mississippi crude. Anon. *World Oil*, Mar. 1952, **134** (4), 214.—Provision is made for the steam heating of particularly heavy crudes, which may otherwise be described as plastic, to enable the transmission from field to terminal. Steam is heated in gas-fired boilers, consuming 4 million cu. ft. gas per day in winter conditions. Along 88 miles of the line heating stations are located approx every 9 miles; in all there exist nine heating stations and four combination heating and pumping stations. In the event of any "freeze-up," mobile units may be made available for the production of extra heating power. The capacities of the 10- and 14-inch lines are 21,000 and 42,000 b.d. respectively. A. J. H.

2274. Methanol as a hydrate inhibitor. R. M. Woolfolk. *Oil Gas J.*, 21.4.52, **50** (50), 124.—The prevention of hydrate formation in the Tremont and Choudrant to Hico-Knowles, La, 18-mile gas line by injection of only 1·85 gal of methanol per million cu. ft. gas is described. Figures show initial and revised facilities in service winters of 1949–50 and 1950–51 respectively.

Cost for methanol only is $0·65 per M.M. c.f. G. A. C.

2275. The pressure surge in oil pipelines. J. E. Green. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 7.—A method is presented of determining the approx pressure of a moving wave caused by instantaneous flow stoppage and the shape of the wave front. A method is also given for determination of the approx response time. The development of certain equations utilized in the methods described is given in an appendix. D. K.

2276. Some technical aspects of the Tacagua products pipeline. I. V. Tullar. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 23.—The Tacagua products pipeline, which connects Caracas with Catia de la Mar, incorporates the latest safety and labour saving devices. A description of the pumping station at Catia la Mar and of the line itself is given. An automatic control system is used to maintain pump operation at the correct speed and shuts down the pumps in an emergency. The pumps are also protected against overheating or pressure loss due to a line failure. The engines shut off if the lubricating oil system fails or the engines overheat for any other reason. Calculations were made to ascertain the maximum possible surge pressure, and results were used in setting the safety factors of the equipment. All line-welds were X-rayed and rejected welds cut out and rewelded. D. K.

2277. Large-diameter high-strength pipe for oil and gas transmission. P. E. Noll. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 29.—The relationships of pipe characteristics to pipeline design are reviewed. Pipes of high strength can be obtained either by manufacturing the pipe from steel with the required physical properties or by cold working of the pipe, *i.e.*, expanded pipe.

The properties and manufacture of expanded pipe are discussed, and the effect of expansion is examined. The effective yield strength of a section of pipe is considered. Many graphs and photographs are included. D. K.

2278. Contamination in pipelines used for transport of petroleum products. P. Lefevre. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 1. (In French.)—Different grades of crude oil and different finished products may be pumped one after another along the same pipeline, whereupon some intermingling will occur and a contamination zone will arise. The length and composition of this zone are functions of certain factors. A theory of contamination has been worked out on the basis of modern studies of liquid flow in pipes. The shape of the composition curve of the contaminated zone and its length, as a function of distance covered in the pipeline and Reynolds No., have been determined. Theoretical results were compared with practical curves obtained from tests made in the U.S.A. and those resulting from experiments carried out in France. It was shown that theory and practical results agreed reasonably well. The theory propounded throws some light on variables to be considered in order to reduce contamination to a minimum. D. K.

2279. Tie-in piping system featuring flexibility, safety. Anon. *Oil Gas J.*, 7.7.52, **51** (9), 66.—System developed by Tennessee Gas Transmission Co. permits orderly addition of loop lines and compressor buildings at compressor stations, and tie-ins are made with no sacrifice of design strength or curtailment of services. Costs are eventually considerably less than conventional method. G. A. C.

2280. Helical displacement in conduits. M. P. Kalinushkin. *Izvest. Akad. Nauk. S.S.S.R., Otdel. Tekh. Nauk*, 1952, 359–66.—Helical movement is general rule, linear displacement being special case of helical displacement with infinite pitch. Various experimental methods for determining angle of air flow in pipes are described and results discussed. Occurrence of helical movement can explain such effects as sudden changes in pressure losses in pneumatic systems. V. B.

2281. General principals of metrology as applied to the petroleum products trade. M. Jacob and E. Befahy. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 88. (In French.)—The advantages and disadvantages of vol and wt units for the sale of petroleum are discussed. The precautions that should be taken when measuring wt or vol and causes of error are reviewed. Methods of measurement, qualifications necessary in those

making the measurements, instruments used, and units are described. Also considered is the mixed parameter, as it plays a part either as a conversion factor or as a measurable element of quality. D. K.

2282. Slippage errors in positive displacement liquid meters. N. Plank. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 100.—Procedure used in making tests on the slippage characteristics of small size meters is described. Laboratory results suggest slippage errors are fairly large and follow definite patterns of visc v. head-loss relationship. Limited field tests indicate slippage characteristics of large meters follow a definite pattern similar to that shown in the laboratory tests on small meters. It is concluded that accurate readings can be obtained from a displacement meter without making test runs each time visc or head loss changes. Fully illustrated by diagrams and photographs; numerous graphs are also included. D. K.

2283. New techniques in the gathering, measurement and sampling of crude oil. B. R. Walsh, E. W. Jacobsen, and R. J. S. Pigott. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 92.—The possible solutions are discussed to the problems encountered in the gathering, sampling, and measurement of well production for control records and cost accounting. The requirements for sampling, methods in use and two new methods are considered. Also described are measurement of flow in gases and liquids, the requirements and limitations for accuracy, the physical conditions and calibration methods necessary to keep the metering instrument in the correct accuracy range. D. K.

2284. Progress in oil measurement standardization in the United Kingdom. H. Hyams. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 64.—The progress of the IP Standardization work, commenced in 1932, is reviewed. Details are given of books and papers published which have contributed to the forthcoming production of the ASTM/IP book "Petroleum Measurement Tables" and the manual of standardized oil measurement procedures. D. K.

2285. Progress in oil measurement standardization in the United States. L. C. Burroughs. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 82.—Review of progress in oil measurement standardization in the U.S. in the last forty years. The ASTM organized a committee in 1940 to prepare complete standards for measuring oil in bulk. This work, done in conjunction with the IP, is almost complete, and is described herein. D. K.

2286. International petroleum tables—their origin, development and practical importance. H. Hyams and H. R. Holmes. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 68.—Early work on the coeff of expansion of petroleum products is described, with particular reference to the work by the U.S. Bureau of Standards resulting in the publication of "Circular C410." Later American work on volume expansion characteristics is also discussed. IP work corresponding to the above American work is then considered.

The ASTM and IP have produced standard tables entered against specific gravity. The practical importance and future development of petroleum tables and tables for blends of petroleum with non-petroleum products are discussed. The appendix gives details of ASTM/IP Petroleum Measurement Tables. D. K.

2287. Questions on technology. W. L. Nelson. *Oil Gas J.*, 23.6.52, **51** (7), 111.—The computation of evaporation losses is illustrated by examples and their solution. G. A. C.

2288. Modern developments in drum making. C. Gelderman. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 50.—A review of drum making during the last thirty years is given. Descriptions of special containers for shipping various petroleum products and consideration of the transport and handling of these containers is included. The quality of steel used in drum making and the painting, decorating, internal coating, and storing of drums are other subjects discussed. D. K.

2289. Patents. U.S.P. 2,585,119 (12.3.48; 12.2.52). R. A. Hanson and F. S. Scott, assrs to Union Oil Co. Hot bitumen is transferred from storage tanks to transport

tanks containing extraneous water without spillage due to sudden evaporation of the water, by adding a small quantity of a dispersion of a silicone in a hydrocarbon oil to the transport tank after it is a quarter to a half full and thereafter continuing the filling of the transport tank. The latter is vented to allow escape of steam.

U.S.P. 2,585,680 (28.10.47; 12.2.52). H. A. Quist, assr to Sun Oil Co. A liquid level gauge for closed pressure vessels.

U.S.P. 2,587,204 (21.5.46; 26.2.52). G. W. Patch and J. G. Van Vleet, assrs to Union Carbide and Carbon Corpn. Railroad tank car for conveying liquefied gas.
J. M. S.

Refinery Operations

Refineries and Auxiliary Refinery Plant

2290. How Shell Oil uses high-pressure water in maintenance construction. J. Vasey. *Oil Gas J.*, 21.4.52, **50** (50), 133.—Portable equipment is used to bring high pressure water to all areas of Shell Oil Co., Wood River refinery. Two pumps take suction from fire line at 150 p.s.i. and can deliver at 67 g.p.m. at 950 p.s.i. and 250 g.p.m. at 150 p.s.i. respectively. Various nozzles are used with cleaning equipment according to work to be performed. Equipment cleaned includes tube bundles, distillation trays, stills; and the method has also been used for boring under-road crossings. G. A. C.

2291. The oil refinery of the N.V. De Bataafsche Petroleum Maatschappij at Rotterdam-Pernis. L. L. W. Van Soest. *Ingenieur*, 20.6.52, **64** (25), A275–8.—A fairly detailed description is given of this Royal Dutch/Shell Group refinery. After emphasizing its economical importance, the crude- and vacuum-oil distillation, the lube oil treatment, the thermal and catalytic cracking plants (with flowsheet of the latter), the chemical plant, and the refinery's power installations are described. G. F. T. C.

2292. The feedwater composition of high-pressure boilers. C. Janssen and J. W. Minken. *Ingenieur*, 4.7.52, **64** (27), Ch67–9.—The current phosphate and caustic methods of keeping the boiler water up to the correct pH-value, and their advantages and disadvantages in relation to the feed-water composition are discussed. The caustic method may result in hydrogen embrittlement of the boiler pipes and the phosphate method in their caking up with hard-baking magnesium sludge. Different methods of keeping the feed water at pH 8·3 to 9·0 are described. G. F. T. C.

2293. Cooling water treatment with surface active materials. W. F. Oxford. *Petrol. Process.*, May 1952, **7** (5), 620–2. (*Natural Gasoline Assn of America, Houston, Apr.* 30, 1952.)—The use of surface-active agents is reported for preventing scale formation and corrosion in the circulating water of gas-compressor plants. The compound used consists of a mixture of a high mol. wt. substituted glyoxalidines, known as Kontol, and an acylated amino alcohol, marketed as SP-8. It is believed that the mixture is also effective in controlling cooling-tower wood delignification. Proposed explanations are given for the function of these compounds in inhibiting corrosion, scale formation, and delignification. Cost data show this system of protection to be much cheaper than conventional methods. D. W. F.

2294. Engineering fundamentals. H. W. Smith. *Oil Gas J.*, 21.4.52, **50** (50), 177.—Pt 1 of this series describes how to select transmission belts; and a table of service factors is given, together with formulæ. G. A. C.

2295. Engineering reference section. Anon. *Oil Gas J.*, 23.6.52, **51** (7), 105.—Pt 11 deals with the operation of reciprocating pumps, with special reference to packing and lubrication. G. A. C.

2296. Engineering reference section. G. L. Farrar. *Oil Gas J.*, 30.6.52, **51** (8), 103; 7.7.52, **51** (9), 99.—Pt 12 concerns operation of rotary pumps, and deals with strainers, suction and discharge piping. A figure shows size of suction pipe recommended for viscous liquids.

Pt 13 deals with operation of centrifugal pumps, and gives notes on priming, starting, stopping, stuffing boxes, and wearing rings. G. A. C.

2297. How to make brass liners work. W. C. Uhl. *Petrol. Process.*, Apr. 1952, **7** (4), 475–7.—Brass liners in steel pipes have been found to fail at the steel to brass brazed joints long before the liner fails. Sketches are given showing how the brazed joints can be protected from the fluid stream in applications such as pipe flanged joints, teed joints, and pressure taps. D. W. F.

2298. Refiner's notebook. S. Chesler and B. W. Jesser. *Oil Gas J.*, 23.6.52, **51** (7), 115; 30.6.52, **51** (8), 111; 7.7.52, **51** (9), 101.—No. 127 in this series shows how to calculate pressure drop when back-pressure relief valves are used, and a chart gives kinetic energy correction for pressure drop for isothermal flow of gases.

No. 128 demonstrates calculation of pressure drop when back-pressure relief valves are used; isothermal and adiabatic solutions being shown.

No. 129 deals with question of open or closed system for relief-valve discharge; and gives a figure showing max ground concentration v. rate of emission for various stock heights. G. A. C.

2299. Patent. U.S.P. 2,585,831 (23.11.46; 12.2.52). L. W. Peterson, assr to Swift & Co. Apparatus for degasifying liquids comprising a degasifying chamber containing a vacuum chamber holding an absorbent material. The released gases are absorbed by the latter and subsequently exhausted from the vacuum chamber. J. M. S.

Distillation

2300. Extractive distillation. J. Chambers. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 90–106.—General discussion of extractive distillation and effect of such variables as reflux ratio, heat input, extractant circulation rate, and feed concentration. Detailed treatment is given to the separation of butane from butene-1 using furfural as solvent. E. J. C.

2301. Variable reflux in multicomponent distillation calculations. W. R. van Wijk and A. H. de Haas van Dorsser. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 87–9.—Discussion of required conditions which permit a distillation at variable reflux to be considered as occurring at constant reflux. E. J. C.

2302. Calculation of number of theoretical plates required for separation of ideal binary mixtures. H. Pohl. *Erdöl u. Kohle*, 1952, **5**, 291–4.—Formulæ are developed mathematically for the No. of theoretical plates for finite and infinite R.F.R. for both continuous and batch operation. Examples are shown, and derivation and theoretical considerations of the formulæ are explained. For infinite R.F.R. tables of general applicability are given. P. V.

2303. Vapour–liquid equilibria and distillation problems—binary and ternary mixtures. R. Haase and W. Jost. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 54–69.—The thermodynamic basis of binary vapour–liquid equilibria is discussed with reference to various systems. Heats of mixing and vapour–liquid equilibria are presented for the systems *cyclo*hexane–*n*-heptane and methyl*cyclo*hexane–*n*-heptane. A discussion of ternary and binary azeotropes is given, and the general theory of distillation and vapour lines for simple ternary mixtures is discussed with reference to the systems benzene–acetone–chloroform and methanol–acetone–chloroform. Problems of azeotropic and extractive distillation are discussed. E. J. C.

2304. Effect of holdup—charge ratio in laboratory batch distillation. A. Rose and V. J. O'Brien, Jr. *Industr. Engng Chem.*, 1952, **44**, 1480–6.—Reports experimental study of the batch distillation of the system *n*-heptane–methyl*cyclo*hexane–heptane at varying reflux ratios. Found that general effects of hold-up in ternary systems were the same as for binary systems. E. J. C.

2305. Vacuum distillation—variables in packed column distillation at subatmospheric pressures. M. S. Peters and M. R. Cannon. *Industr. Engng Chem.*, 1952, **44** (6), 1452–9.—Effects of reduced pressure on column efficiency, pressure drop, and max allowable vapour velocity were determined for 0·16 × 0·16-inch and 0·24 × 0·24-inch stainless steel protruded packings, 0·25-inch stainless steel 100-mesh screen McMahon packing, and 0·25-inch ceramic Berl saddles. Efficiencies of protruded packings and McMahon packing increased with reduced pressure, but efficiency of Berl saddles was substantially constant with varying pressures. Pressure drop per unit height increased in all cases as operating pressure was reduced for a given boil-up rate. E. J. C.

2306. Calculation of packed distillation columns. F. J. Zuiderweg. *Ingenieur*, 4.7.52, **64** (27), Ch63–6.—A number of recent papers on the calculation of packed distillation columns are critically reviewed. The unsatisfactory situation as regards the calculation of the separating power of these columns is indicated. Simple relations are given for flooding limit and H.E.T.P. value of Rashig ring packed columns. G. F. T. C.

2307. The new " Benturi " fractionator tray. D. P. Thornton. *Petrol. Process.*, May 1952, **7** (5), 623–7.—Cut-away diagrams are given of both the original Koch " kaskade " type of tray and of the new " Benturi " tray. The new design differs mainly in that the vapour entry to the tray is in the form of a series of parallel venturi slots bent through 90° so that the vapour enters the liquid on the tray horizontally, carrying liquid with it on to vertical gauze retaining screens. The relative areas of slot and downcomer can be varied very considerably, thus making the design flexible for a wide range of vapour and liquid loads.

Comparative data are given for the operation of a Benturi tray and a bubble tray high-pressure absorber in a natural-gasoline plant under identical conditions. Under a loading test the Benturi tower showed a much greater allowable vapour throughput. Further data are given on a low-pressure absorber and also efficiency tests when used for solvent extraction with the system furfural–*cyclo*hexane–water. With the column inverted and hydrocarbon phase dispersed tray efficiencies of 21 to 44% were obtained. A chart is included for evaluating tower dia for given throughputs and tray spacing. D. W. F.

2308. Patents. U.S.P. 2,585,202 (24.5.48; 12.2.52). W. B. Whitney, assr to Phillips Petroleum Co. Apparatus for distillation under high vacuum.

U.S.P. 2,587,260 (27.5.48; 26.2.52). W. B. Whitney, assr to Phillips Petroleum Co. Apparatus for molecular distillation. J. M. S.

2309. Patents. Ger.P. 830,502, 3.1.52. K. C. D. Hickman, assr to Eastman Kodak Co. Apparatus for obstacle-free distillation in the high vacuum.

Ger.P. 831,392, 10.1.52. O. Grosskinsky and W. Klempt, assrs to Kohlentechn. G.m.b.H. Procedure for the working up of benzene first runnings.

Ger.P. 831,730, 17.1.52. G. Free and O. Göhre, assrs to Bad. Anilin- & Soda-Fabr. Procedure for the production of oils of medium boiling range from crude oils and crude oil residues. (Addn. to No. 821,988.)

Ger.P. 832,650, 24.1.52. K.-H. Struck, assr to Dr C. Otto & Comp. Procedure for separation of naphthalene from distillation gases.

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Absorption and Adsorption

2310. Adsorption—a review of recent process trends. J. A. Berriman. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 174–83.—Use of adsorption in oil refining is outlined with particular reference to the contact process, the gas phase adsorption of hydrocarbons, and liquid-phase adsorption. In each case some of the variables affecting the particular process are discussed. E. J. C.

2311. The hypersorption process for gas fractionation. C. Berg. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 184–95.—Discusses basic features, design, and method of operating hypersorption units for separation of gases. Plant is described by reference to flow diagrams and sketches of column details. Performance data of commercial units are tabulated, and it is pointed out that the process is applicable to other separations as well as the separation of hydrocarbons. E. J. C.

2312. Patents. U.S.P. 2,585,490 (31.3.49; 12.2.52). U.S.P. 2,585,491 (14.4.49; 12.2.52). U.S.P. 2,585,492 (14.4.49; 12.2.52). J. L. Olsen, assr to Sun Oil Co. All describe continuous adsorption processes for separating liquid mixtures by means of a moving particulate adsorbent.

U.S.P. 2,586,889 (23.8.49; 26.2.52). H. G. Vesterdal and W. H. Konrad, assrs to Standard Oil Development Co. Straight-chain hydrocarbons are separated from branched-chain and cyclic hydrocarbons by preferentially absorbing them on activated carbon prepared by treating acid sludge coke with steam at 1350° to 1500° F. J. M. S.

Solvent Extraction and Dewaxing

2313. Extraction of mercaptans from light distillate fuels. R. L. Yahnke, J. H. Krause, and G. H. Weismann. *Industr. Engng Chem.*, 1951, **44**, 1486–9.—Reports a bench-scale and pilot-plant scale study of the extraction of mercaptans from a light petroleum distillate using caustic alkali and methanol as solvent. Addition of cresylic acid was found to improve the efficiency of the solvent for mercaptan removal. Flow sheet given. E. J. C.

2314. Solvent extraction tests and their assessment with reference to lubricating oil refining. M. Freund and A. Vámos. *Erdöl u. Kohle*, 1952, **5**, 283–90.—Customary methods of evaluating solvent extraction processes such as miscibility, yield, and phase-diagrams are verified and extended as a result of numerous single stage laboratory experiments carried out under various conditions using 7 lub oil dist (from same mixed-base crude) and various solvents (furfural, aniline, nitrobenzene, *o*-cresol, do + 5% H_2O, SO_2 + 5% C_6H_6). Properties of the ultimate products prepared by exhaustive extraction and by chromatographic fractionation do not correspond to those graphically determined. Thus the foundation for the conventional construction of phase diagrams appears to be unreliable. In contradiction to previous theories, it is claimed that solvent selectivity, though largely dependent on extraction conditions, should not be considered as a characteristic of the solvent but rather as that of a given process. A generally valid relationship between the selectivity and solvent power of a solvent is postulated, according to which, independently of extraction process conditions, the selectivity increases as solvency decreases, *i.e.*, given values of the former always correspond to the same values of the latter. The limits of validity and possible applications of this correlation are described. P. V.

2315. The use of extraction processes in the manufacture of lubricating oils. E. J. Dawson. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 107–19.—Principles of solvent extraction are briefly discussed followed by descriptions of the sulphur dioxide, furfural, phenol, and Duosol processes. Flow sheets are given, advantages and disadvantages of each process discussed, and methods of overcoming operational difficulties indicated. E. J. C.

2316. A new efficient extraction apparatus: the rotating disk contactor. G. H. Reman. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 121–31.—Description of a new type of solvent extraction apparatus which is claimed to be very efficient and flexible. Results given include those for effect of a number of variables on capacity and efficiency using the system *iso*butyl ketone–water–acetic acid. Practical extractions, such as extraction of a lub oil distillate with furfural, are also cited. E. J. C.

2317. Report on a new dewaxing agent (precipitator/solvent couple). H. Poell. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 156–60.—Combination of 1 : 1-dichloroethane and 1 : 2-dichloroethane is stated to give a precipitator/solvent couple very suitable for

centrifugal dewaxing, at least equivalent to acetone/benzole, which is most normally used for dewaxing with filtration. As the two dichloroethanes do not form an azeotrope and differ appreciably in b.p. they can easily be separated by distillation. Results of tests carried out on various stocks are tabulated and solvent ratios initiated according to the type of stock used. E. J. C.

2318. Furfural extraction of middle distillates. W. P. Gel, H. H. Gross, and W. E. Skelton. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 132–44.—Describes furfural extraction of catalytically cracked gas oil for production of high quality diesel oil, domestic heating oil, and as a charge stock for cat cracking. Data on untreated and treated stocks are given, together with results of engine tests on the diesel oil produced. Description and flowsheet of an industrial installation are also included. E. J. C.

2319. Hydrogen fluoride extraction of sulphur compounds and high sulphur petroleum stocks. A. P. Lien, D. A. McCaulay, and B. L. Evering. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 145–55.—Reports experiments on removal of sulphur compounds from synthetic blends of organic sulphur compounds in heptane, and from petroleum stocks using anhydrous H.F. Mechanism of the action is discussed by reference to the formation of a sulphonium salt. Degree of extraction of the sulphur compounds was found to be dependent upon basicity and b.p. of the sulphur compound. Extraction increased in going from mercaptans to disulphides and sulphides. In all cases extraction decreased with b.p. E. J. C.

2320. Patent. U.S.P. 2,583,620 (28.6.47; 29.1.52). J. M. Wrightson, assr to The M.W. Kellogg Company. A solvent extraction process for removing oxygenated hydrocarbons from a mixture thereof with hydrocarbons obtained by hydrogenation of carbon oxides, the extraction solvents used being a glycol, a light alcohol, and water. R. C. R.

2321. Patent. U.S.P. 2,584,966 (10.9.48; 5.2.52). E. J. Reeves, assr to Socony-Vacuum Oil Co. Inc. A method of dewaxing oils using a dewaxing solvent containing an aqueous contaminant is described. Special steps are taken to avoid the formation of hard, adherent ice in the shock-chilling stage. J. M. S.

Cracking

2322. Three actual cases demonstrate flexible refinery operation. G. L. Withers. *Oil Gas J.*, 30.6.52, **51** (8), 56.—The Numex refinery of the New Mexico Asphalt and Refining Co., Artesia, N.M., operates its T.C.C. unit according to three plans. In the first all refining units are utilized to give balanced yields of straight-run and catalytically cracked products. In the second all crude is charged to T.C.C. unit, eliminating several operations, improving O.N., and accomplishing maintenance turnaround of idle units without diminishing product quality. The third plan arranges for addition of topped crude and straight-run gasoline to whole crude, resulting in production of desired straight-run fraction and even great O.N. improvement. G. A. C.

2323. Hydroforming with fluid-bed catalysts. P. W. Sherwood. *Erdöl u. Kohle*, 1952, **5**, 295–6.—Brief general description of hydroforming process; best feed is naphthene-rich C_{7-8}; operating pressure is 200 to 400 p.s.i. at 480° to 540° C; contact time with chrome/alumina cat is 15 sec. Prevalence of dehydrogenation reactions make external supply of H_2 unnecessary, and excess of H_2 can be made available to other plants. Cat regeneration section is much smaller than for fluid cat crackers, as C formation is much less (1½ to 2% on feed). Advantage of fluid bed over fixed is steadier temp, latter can vary by as much as 65° C in fixed bed. Yield with fluid bed is 5% greater than with fixed, although latter is more suitable for small installations. V. B.

2324. Contribution of the Houdry processes to petroleum refining. W. F. Farragher, H. D. Noll, and R. E. Bland. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 138–56.—The history of catalytic cracking is developed, with emphasis on development and commercialization of the Houdry processes. A description of a typical design of the

Houdriflow process is included. Typical yield and economic data show five ways of applying Houdriflow principles to a hypothetical refinery charging 25,000 b.s.d. of Iraq crude. D. H.

2325. Catalyic cracking of high nitrogen charge stock. J. W. Schall and J. C. Dart. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 106–23.—Crude fed to a moving bed pilot plant was 21·2° API gravity, 910° F E.P. gas oil containing 0·4% nitrogen. The effects of cracking temp, recycle ratio, and catalyst to oil ratio on product distribution and quality are deduced. The nitrogen distribution in product streams is given.

A series of combination charts allows extension to any other feed stock of high nitrogen content. D. H.

2326. Catalytic cracking of pure compounds and petroleum fractions. H. H. Voge, G. M. Good, and B. S. Greensfelder. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 124–37.—Results from forty-one pure hydrocarbons show the reactions which occur and the products to be expected from the cracking of petroleum fractions of various compositions. Mixtures of pure hydrocarbons are found to crack as predicted, with minor exceptions. The strong inhibition of cracking by nitrogen bases and the lack of effect of oxygen on sulphur compounds are illustrated.

Gasoline yields under fixed cracking conditions may be predicted from data presented, provided nitrogen bases are absent or are removed by acid washing.

Studies of coke formation from pure hydrocarbons under fixed conditions place aromatics in the highest position; this is in accord with results from petroleum stocks. D. H.

2327. Catalytic cracking and reforming processes for increasing the yield and octane number of gasoline. S. D. Dalton and T. P. Simpson. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 157–65.—The Thermofor catalytic reforming process is summarized, and typical yield data are given for T.C.C. processing of several feedstocks. The variables affecting cracking and the economics of a high-conversion recycling catalytic cracking unit are examined. D. H.

2328. Factors affecting octane numbers of catalytically cracked gasolines. E. F. Schwarzenbek, C. E. Slyngstad, P. T. Atteridg, and J. W. Jewell. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 167–75.—The ASTM and CFR O.N.s of clear and leaded gasolines produced over silica–alumina catalysts are increased by increases in feed conversion, operation temp, steam concentration, throughput ratio at a given total feed conversion; and by decreases in operating pressure, catalyst activity, feedstock 20% b.p. (naphtha free), and feedstock boiling width.

Prediction charts enable the estimation of O.N. of the gasolines to within 0·5 numbers. The blending properties of catalytic gasolines can be approximated by a simplified Eastman method. D. H.

2329. Operating variables and reactions in suspensoid cracking. R. K. Stratford and C. H. Caesar. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 176–83.—The suspensoid process employs small amounts of catalyst in coil type tubular reactors similar to those in conventional thermal cracking. The effects of operating variables are shown by results on a Mid-Continent crude.

The process is also suitable for polymerization, alkylation, hydrogen transfer, and production of branched-chain paraffins and aromatics. D. H.

2330. Kinetics of regeneration of alumino-silicate catalysts. Reaction mechanism of oxidation of " coke " on alumino-silicate catalysts. G. M. Panchenkov and N. V. Golovanov. *Izvest. Akad. Nauk S.S.S.R., Otdel. Tekh. Nauk*, 1952, 384–94 (*cf.* Abs. No. 723).—Apparatus used was as in previous investigation. In temp range 270° to 450° C initial effect of contacting coked cat with O_2-containing gas is wt increase due to O_2 absorption, rate of which increases linearly with temp, then changing to decrease as oxidn occurs. At O_2 concn $>30\%$ oxidn reaction is of first order, at higher O_2 concn reaction tends to zero order. Kinetics of process are considered and equation derived for rate of oxidn to CO_2 and CO. Agreement of theoretical curves (wt decrease against time) thus obtained with experimental results is demonstrated. Energy of

activation of formation of initial complex is 11,500 cal/mol and of decomposition 35,000. V. B.

2331. Production of high-purity aromatics for chemicals. D. Read. *Oil Gas J.*, 23.6.52, **51** (7), 82.—A summary of paper presented at API seventeenth mid-year meeting, San Francisco, 1952; and deals with Platforming and Udex extraction units run for production of aromatics previously obtained from coal tar.

Flow sheets and pilot plant data are given. G. A. C.

2332. Patents. U.S.P. 2,584,102 (17.10.49; 5.2.52). J. M. Mavity, assr to Universal Oil Products Co. Catalytic material with improved activity for hydrocarbon conversion is obtained by treating a calcined composite of an acid of phosphorus on a solid carrier with from 1 to 10% by wt of phosphorus pentachloride, phosphorus oxychloride, or phosphorus trichloride, and further calcining at 100° to 550° C.

U.S.P. 2,584,148 (28.5.46; 5.2.52). G. A. Mills, assr to Houdry Process Corpn. Clay catalyst is made by subjecting raw kaolin to treatment with mineral acid, forming into pellets, calcining the pellets at a temp above 500° F, treating them with dilute sodium hydroxide solution, washing and drying the treated pellets, and finally contacting them with an aluminium salt solution.

U.S.P. 2,584,286 (11.3.44; 5.2.52). J. A. Pierce and C. N. Kimberlin, assrs to Standard Oil Development Co. A continuous process for preparing dry adsorbent alumina gel catalysts in spherical form by emulsifying alumina sol in mineral oil, maintaining the emulsion at a temp between 150° and 200° F sufficiently long to cause the sol to set to a hydrogel, maintaining the hydrogel at the same temp until the water has evaporated off, leaving dry spherical particles of alumina gel in the oil, separating the particles from the oil, and returning the oil to the emulsifying step. An inert gas is passed through the oil to assist water removal.

U.S.P. 2,584,378 (23.12.49; 5.2.52). J. Beam, assr to Universal Oil Products Co. In a contacting process in which a stream of fluid is passed upwardly through a fluidized bed of solid particles in a reaction zone and the solid particles are transferred from the reaction zone to a regeneration zone, the particles are withdrawn downwardly from the reaction zone in a dense phase and discharged into a transfer conduit disposed transversely with respect to the reaction zone and communicating with the regeneration zone, and two jet streams are maintained in the conduit, one being directed upwardly into the reaction zone, hindering the discharge of particles therefrom, and the other being directed away from the reaction zone and towards the regeneration zone.

U.S.P. 2,584,391 (29.3.47; 5.2.52). F. W. Leffler, assr to Universal Oil Products Co. An apparatus for fluidized catalytic cracking is a vertical chamber containing a continuous partitioning wall, the zone inside the wall being the reaction zone and the annular zone between the said wall and the walls of the chamber forming a recycle zone. The partitioning wall terminates some way below the top of the chamber to provide a separation zone.

U.S.P. 2,584,405 (27.12.49; 5.2.52). J. P. West, assr to Universal Oil Products Co. A catalyst suitable for hydrocarbon conversion is made by a metathesis reaction of an alkyl orthosilicate, a boric acid ester, and an aluminium or magnesium salt of an organic acid. The reaction is carried out at a temp $< 150°$ C but below the decomposition temp of the salt.

U.S.P. 2,584,756 (11.8.48; 5.2.52). H. M. Stine, assr to Socony-Vacuum Oil Co. Inc. A catalyst for reforming hydrocarbons is made by heating a mixture of beryllium, ferric, and aluminium oxides in the mole ratio 10 : 10 : 80 at a temp of 1150° to 1500° F. The catalyst increases the proportion of aromatics and unsaturates in hydrocarbon mixtures under reforming conditions.

U.S.P. 2,585,238 (23.10.48; 12.2.52). C. G. Gerhold, assr to Universal Oil Products Co. Method and apparatus for fluidized catalytic conversion involving a lower contacting zone, an upper contacting zone, and a particle storage zone superimposed above the latter.

U.S.P. 2,585,274 (22.12.44; 12.2.52). E. H. Reichl, assr to Stanolind Oil and Gas Co. A catalytic reactor with a number of separately controllable cooling units vertically suspended within the reaction and catalyst separation chambers.

U.S.P. 2,585,441 (22.12.47; 12.2.52). P. W. Cornell and E. Cotton, assrs to Gulf Oil Corpn. Apparatus for catalytic reactions comprising two horizontal elongated cylindrical shells closed at both ends, one being centrally placed inside the other, the inner shell containing a fixed catalyst bed. Impellers in the outer shell force fluids downwardly into the inner shell and through the catalyst bed, and upwardly in the space between the shells. A heat exchanger is placed in the path of flow of the fluid.

U.S.P. 2,585,462 (19.12.47; 12.2.52). J. H. Hirsch, assr to Gulf Research & Development Co. Apparatus for catalytic reactions enabling fluid reactants to be circulated downwardly through a fixed catalyst bed and over a heat exchanger is described.

U.S.P. 2,586,705 (14.2.48; 19.2.52). J. S. Palmer, assr to Standard Oil Development Co. Fluidized catalytic cracking apparatus with improved means for passing catalyst from the reactor to the regenerator.

U.S.P. 2,587,425 (30.4.49; 26.2.52). C. E. Adams and C. N. Kimberlin, assrs to Standard Oil Development Co. Naphtha is reformed by passing it through a fixed bed of activated carbon at 900° to 1100° F. The latter is regenerated by treatment with steam at 1000° to 2000° F.

U.S.P. 2,587,554 (23.10.45; 26.2.52). J. Weikart, assr to Standard Oil Development Co. Apparatus for stripping finely divided solids after they have been contacted with gases in a reaction vessel. J. M. S.

2333. Patents. Ger.P. 829,343, 20.12.51. Roman Schestopal, Gundelsheim. Procedure for the cracking of petroleums, tar, and coal tar.

Ger.P. 831,576, 17.1.52. H. Tramm and H. Kolling, assrs to Ruhrchemie A.G. Procedure for cracking aliphatic hydrocarbons.
Brennstoff-Chem., 1952, **33** (3–4). R. T.

Hydrogenation

2334. Hydrogenation of carbon monoxide in liquid phase. H. Kölbel and P. Ackerman. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 2–14.—The advantages of suspending the iron catalyst in oils are increased flexibility, better dissipation of heat of reaction, increased space–time yield, etc. The operating conditions of the reactor, 2·5 m dia and 5 m high, are compared with those of fixed-bed convertors. Particle size, concentration, and preparation are described, and the effects of several variables on product composition indicated. D. H.

2335. Progress in the hydrogenation of petroleum oils. M. Pier. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 81–90.—The German hydrogenation of residual oils at 300 and 500 atm and the use of fixed-bed hydrogenators running on lignite tars to give diesel fuel, lub oils, and waxes is reviewed.

Data are reported on direct splitting of crude and topped-crude oils by a single vapour-phase conversion in a fixed bed. The same results are claimed without the need for preliminary liquid-phase hydrogenation. D. H.

2336. High pressure hydrogenation as applied in the processing of crude oils in Germany. R. Becker. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 68–80.—The conversion of hydrogenation plant to handle a paraffinic residual oil showed that its capacity was twice that when treating coal. The Middle East and German crudes fed are compared, and small differences in water, salt, and sulphur content are shown to be of importance in hydrogenation.

Operating conditions and their effect on product yield and properties are detailed. Gasolines of 65 O.N. clear, 75 leaded, yield 80%, and are suitable for blending with straight-run gasoline to give total yield from Aramco crude of 60% gasoline (flow sheets given).

Hydrogenation is shown to be a useful adjunct to cracking units. Overall thermal efficiency of 66% is claimed. D. H.

2337. Catalysis in liquid-phase coal hydrogenation. S. Weller and M. G. Pelipetz. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 91–7.—Certain phases of the catalysis of the

liquid phase hydrogenation of coal have been studied in a batch autoclave at U.S. Bureau of Mines. Materials such as nickelous chloride and ammonium molybdate, which appear to be almost non-catalytic when added as powder, become comparable with stannous chloride when impregnated on the coal from aqueous solution.

The effects of the constituents of ash, the stability of the catalysts, and the anion in the catalyst have been studied. Some of the implications of these results and some of the questions raised by them are discussed. D. H.

2338. Selective hydrogenation of sulphur compounds from highly unsaturated cracked gasoline. C. G. B. Hammar. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 295–307.—For the catalytic removal of thiophenes from gasoline, hydrogenating conditions are necessary. This, however, results in saturation of the olefins and a decrease in O.N.

The reaction kinetics of the simultaneous hydrogenation of thiophenes and olefins have been studied, and the results indicate that the two reactions may occur on different parts of the catalyst. The possibility of a catalyst capable of inhibiting one reaction and hastening the other is indicated. Fifteen catalysts have been tested so far, but none is selective enough to be used commercially. D. H.

2339. Patents. U.S.P. 2,584,531 (9.2.50; 5.2.52). H. R. Arnold and J. E. Carnahan, assrs to E.I. du Pont de Nemours & Co. Organic compounds are hydrogenated by contacting them at a temp of 25° to 500° C with hydrogen and a metal salt of H_2MoO_3 or H_2MoO_4.

U.S.P. 2,585,337 (15.2.49; 12.2.52). J. B. McKinley, assr to Gulf Research & Development Co. Hydrocarbon oils are destructively hydrogenated in presence of a catalyst prepared by impregnating a silica–alumina cracking catalyst with an aqueous solution of molybdenum pentachloride and drying and calcining the resultant mass to convert the impregnant into molybdenum trioxide. The calcined catalyst should contain 0·5 to 4·0% molybdenum trioxide.

U.S.P. 2,586,535 (29.12.48; 19.2.52). V. N. Ipatieff and H. Pines, assrs to Universa Oil Products Co. Benzene hydrocarbons are hydrogenated at 200° to 400° C at a pressure of 50 to 200 atm in presence of stainless steel containing nickel and chromium and of a catalyst comprising copper and alumina.

U.S.P. 2,587,149 (10.2.48; 26.2.52). M. H. Gwynn. Hydrofining hydrocarbons in presence of an iron, cobalt, nickel, or copper compound, regenerating the catalyst by oxidation to form the metal sulphate followed by reaction with a strongly alkaline compound to form a readily reducible basic compound of the metal, and using the regenerated catalyst in the last hydrofining stage. J. M. S.

Polymerization

2340. An improved process for polymerization of olefins with phosphoric acid on quartz catalyst. G. E. Langlois and J. E. Walkey. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 191–200.—Flowsheets and design data are presented for polymerization of C_3 to C_4 olefins to produce motor gasoline. The catalyst, which consists of a film of phosphoric acid on crushed quartz, has the advantage of low cost, high mechanical strength, and ease of regeneration.

The results of pilot plant investigations show the optimum operating conditions for any given feedstock. D. H.

2341. Polymerization with solid phosphoric acid catalyst. G. Egloff and P. C. Welnert. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 201–14.—Flow sheets and operating variables are given for three catalytic polymerization plants. Feedstocks consist of the light olefin gases from thermal and catalytic cracking and thermal reforming.

Pressure and temp of operation can determine whether maximum yield of olefin or a lower yield of *iso*-octanes will be produced. D. H.

2342. Patents. U.S.P. 2,585,867 (5.3.48; 12.2.52). W. J. Sparks and R. M. Thomas, assrs to Jasco Inc. A mixture of a mono-olefin and a multi-olefin is polymerized at −40° to −103° C in presence of a boron fluoride solution in methyl chloride. The products have a mol. wt. range of 25,000 to 150,000.

U.S.P. 2,586,322 (3.6.50; 19.2.52). W. A. Franta, assr to E.I. du Pont de Nemours and Co. Ethylene is polymerized at 140° C and under a pressure of *ca* 1200 atm in presence of 300 p.p.m. benzol peroxide, 2·3 parts of water, 0·16 parts of benzene, and 0·04 parts of *cyclo*hexane per part by wt of ethylene.

U.S.P. 2,586,594 (29.10.47; 19.2.52). E. Arundale, A. H. Gleason, and F. W. Banes, assrs to Standard Oil Development Co. Drying oils are made by polymerizing a conjugated diolefin of 4 to 6 carbon atoms at 50° to 150° C at a pressure of 3 to 30 atm in presence of a catalyst of the formula $RC(CH_3)_2OOR'$, where R = methyl or phenyl and R′ = benzoyl or hydrogen.

U.S.P. 2,586,852 (6.11.47; 26.2.52). J. C. Morrell. Catalyst suitable for polymerizing olefins consists of a mixture of phosphoric acid and kaolin baked at a high temp. J. M. S.

Alkylation

2343. Revamping an H.F. alkylation unit. F. L. Resen. *Oil Gas J.*, 7.7.52, **51** (9), 84.—A description is given of revision of Swenny, Texas, unit of Phillips Petroleum Company; including catalytic defluorination, vent gas absorption, propylene alkylation, propane stripping, and modification to acid contactors and bauxite driers. Present production 3150 b.d. G. A. C.

2344. How control of alkylate quality affects aviation-gasoline yield. N. N. Feller and R. M. France. *Oil Gas J.*, 16.6.52, **51** (6), 254.—Cities Service Co. have developed an index for measuring alkylate quality. Results indicate that principal factor involved for any specific olefin is internal *iso*butane to olefin ratio. A number of charts show relation between this and external ratio, and *iso*butane purity; lean and rich mixture ratings, and inspection data of components and finished aviation blends. G. A. C.

2345. Patents. U.S.P. 2,584,103 (16.7.49; 5.2.52). H. Pines and V. N. Ipatieff, assrs to Universal Oil Products Co. Alkylated aromatic hydrocarbons are made by reacting an aromatic hydrocarbon with an olefin-acting compound in presence of a reaction product of alumina and a hydrogen halide containing 0·5 to 30% by wt of halogen combined with the alumina.

U.S.P. 2,585,983 (4.12.48; 19.2.52). C. E. Adams, W. A. Proell, and E. G. Ballweber, assrs to Standard Oil Co. Aromatic hydrocarbons are alkylated by reaction with an olefinic hydrocarbon fraction containing neutral oxygenated organic compounds, *e.g.*, ketones, in presence of an alkane sulphonic acid catalyst at 230° to 300° F. Water formed by dehydration of the oxygenated compounds is continually distilled out of the reaction zone with some aromatics, the latter being returned to the reaction zone. J. M. S.

Isomerization

2346. Patents. U.S.P. 2,583,739 (22.1.46; 29.1.52). J. D. Kemp and A. E. Stickland, assrs to California Research Corpn. Producing triptane by catalytic isomerization of *iso*heptanes wherein a liquid feedstock comprising methyl hexanes and dimethyl pentanes is contacted with a catalyst consisting of HF + 5 to 25% BF_3 at 25° to 75° F and in the presence of 6 to 12 vols of liquid propane per vol of feedstock.

U.S.P. 2,583,740 (22.1.46; 29.1.52). J. D. Kemp, assr to California Research Corpn. Isomerizing *n*-heptane by contacting 1 vol of *n*-heptane + 2 to 4 vols of *iso*butane with an HF/BF_3 catalyst and thereafter separating an *iso*heptane concentrate comprising methyl hexanes and dimethyl pentanes, which is then contacted with an HF/BF_3 catalyst in the presence of 6 to 12 vols of liquid propane per vol of *iso*heptane concentrate. R. C. R.

2347. Patent. U.S.P. 2,585, 899 (2.7.47; 12.2.52). G. E. Langlois, assr to California Research Corpn. Dialkyl benzenes are isomerized by contacting with a solid isomerization catalyst containing phosphoric acid at 400° to 1100° F and at a space velocity of 0·05 to 5·0 vols liquid dialkyl benzene per vol catalyst per hr. J. M. S.

2348. Patent. Ger.P. 829,164, 20.12.51. Standard Oil Development Co. Procedure for conversion of normal paraffin hydrocarbons into *iso*paraffin hydrocarbons by isomerization.

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Chemical and Physical Refining

2349. New Autofining process. Anon. *Petrol. Process.*, Apr. 1952, **7** (4), 467–9.—A description, consisting chiefly of extracts from patent specifications, is given of a fixed-bed catalytic desulphurization process, developed by Anglo-Iranian Oil Co. to the stage of a 3500-b.d. plant now under construction at their Llandarcy, Wales, refinery. The catalyst is of the cobalt–molybdate type, stable and sulphur resistant. Pressure, 50 to 200 p.s.i.g., and temp, 700° to 800° F, are controlled to produce sufficient hydrogen from the dehydrogenation of feed naphthenes for the conversion of feedstock sulphur to H_2S. It is applicable to a wide range of high sulphur feedstocks. It may be desirable in some cases to desulphurize a long distillate before fractionation. Pilot plant feed and product data are included on autofining of Middle East straight run gasoline, naphtha, kerosine, and gas oils, long distillate, and aromatic SO_2 extracts. Sulphur removal 98 to 99% for above feeds, except gas oil, 70%, and long distillates, 84%. D. W. F.

2350. Desulphurization of low boiling distillates. E. F. Schwarzenbek, C. E. Slyngstad, and J. A. Knaus. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 274–81.—Desulphurization of low-boiling distillates was investigated by passing the oils over silica–alumina catalysts with no extraneous hydrogen.

Effects of operating temp, space velocity, feed boiling range, catalyst type, and feed sulphur type were investigated in a fluidized catalyst pilot plant. Removal of 60 to 80% was reported in feeds where sulphur was mainly in aliphatic molecules, but only 15 to 30% where sulphur was mainly aromatic. D. H.

2351. Desulphurization of gas oils by hydrogenation and by extraction. H. Hoog, G. H. Reman, and W. C. B. Smithuysen. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 282–94.—The removal of sulphur by extraction with HF and SO_2 is studied in detail, and is compared with removal by hydrogenation. The determination and identification of sulphur compounds in gas oils is surveyed. (Author's Abstract.)

D. H.

2352. Gasoline sweetening operations, Palembang refinery. E. C. Campioni and J. P. Cordia. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 254–62.—A double stage sweetening process has been developed for gasoline of copper No. 6 to 8, using the equipment formerly used for doctor sweetening.

The quality of product is such that after storage with a phenylenediamine type inhibitor the copper No. averages 1·0. The lead response is good.

An economic analysis shows that the major saving is from a reduction in loss of product. D. H.

2353. Complexes of urea and *n*-paraffins. Structure, properties, and application in extractive crystallization. W. A. Bailey, Jr., R. A. Bannerot, L. C. Fetterly, C. M. Gable, R. W. Millar, O. Redlick, and A. E. Smith. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 161–73.—Structure and thermodynamic properties of urea–*n*-paraffin complexes are discussed, and their application to the industrial separation of *n*-paraffins from other hydrocarbons is described by reference to a flow-sheet. E. J. C.

2354. Patents. U.S.P. 2,584,248 (13.7.48; 5.2.52). R. E. Barieau, assr to California Research Corpn. Sulphur compounds are removed from petroleum oils by first extracting the oil with a mineral acid of a concn $\geq 80\%$ by wt and then extracting the raffinate with hydrofluoric acid of a concn $\leq 85\%$ by wt.

U.S.P. 2,585,244 (19.9.47; 12.2.52). O. M. Hanson, assr to Universal Oil Products Co. Thermal diffusion apparatus.

U.S.P. 2,585,284 (7.8.48; 12.2.52). T. B. Tom and J. A. Bolt, assrs to Standard Oil Co. Mercaptans are removed from petroleum distillates boiling in the range 350° to 600° F by contacting with an aqueous methanol solution of an alkali metal hydroxide containing an alkali metal salt of an alkoxyalkylcarboxylic acid of from 4 to 8 carbon atoms.

U.S.P. 2,585,652 (8.2.47; 12.2.52). H. D. Hartough, P. D. Caesar, and S. J. Lukasiewicz, assrs to Socony-Vacuum Oil Co. Inc. Mineral oils containing acidic constituents are contacted with an anion-exchange material obtained from a condensation product of thiophene, formaldehyde, and ammonia, urea, or ethylene diamine.

U.S.P. 2,585,874 (27.5.49; 12.2.52). C. W. Stratford, assr to Stratford Engineering Corpn. Lubricating oil distillates are treated as follows: heating, dehydrating and de-aerating, subjecting to acid treatment, removing volatile sulphur compounds in the vapour phase under reduced pressure, washing with water, neutralizing, and finally washing with water.

U.S.P. 2,585,895 (17.3.50; 12.2.52). P. F. Dougherty and C. H. Brooks, assrs to Sun Oil Co. Petroleum wax is deodorized and decolorized by mixing the molten wax with clay, heating to a temp 50° to 300° F above m.p. of the wax, flashing the mixture into a pressure of 0·5 to 2·0 p.s.i.; quenching to a temp 20° to 40° F above m.p. of the wax, continuing to contact the wax and clay for ¼ to 3 hr and then separating wax and clay by vacuum filtration.

U.S.P. 2,586,198 (5.1.48; 19.2.52). P. S. Backlund and P. L. Polizzotto, assrs to Union Oil Co. Wax is decolorized by contacting in the molten state with magnesia, extracting the mixture with an aliphatic alcohol, ketone, or ether having at least 6 carbon atoms and removing the solvent from the extracted wax.

U.S.P. 2,586,777 (31.1.47; 26.2.52). R. Bond, assr to Houdry Process Corpn. Olefins are removed from hydrocarbon fractions boiling up to 600° F by contacting such fractions with nitrogen tetroxide at 70° to 100° F, destroying excess nitrogen tetroxide, steam distilling, and washing the distillate with caustic solution.

U.S.P. 2,586,947 (29.11.49; 26.2.52). L. A. Hays and R. B. Selund, assrs to Standard Oil Co. Petroleum oils in propane solution are treated with a solid adsorbent to improve their colour. The method consists of slurrying the adsorbent in previously treated oil, mixing the slurry with the propane–oil solution, heating to 200° to 400° F, and separating the propane. J. M. S.

Special Processes

2355. Petrochem report: Shell Chemical Co., Houston. F. L. Resen. *Oil Gas J.*, 23.6.52, **51** (7), 72.—This is the first of a series on petrochemical plants in the Gulf Coast area, and reviews current expansion of the Houston plant by addition of butyl alcohol and M.E.K. History of synthetic glycerine production and some uses of petrochemical products are given. G. A. C.

2356. A new venture in petrochemicals. Anon. *Petrol. Process.*, Apr. 1952, **7** (4), 489–97.—With the commencement of a new section devoted to the petrochemical industry, four introductory articles are included, prepared by the editorial staff of the journal. The articles review the present situation of the industry, and are: What is a petrochemical?; How big will the industry grow?; Stability of supplies and prices are petrochemicals big assets; Where the industry stands to-day, and who's doing what in it. The last article contains data on product sales values of some U.S. companies, production in 1943, and production, sales, and value in 1950. D. W. F.

2357. U.S. petrochemical operations. Anon. *Petrol. Process.*, Apr. 1952, **7** (4), 509–20.—A comprehensive directory is presented of facilities in the U.S. for the manufacture of petrochemical products; benzene, toluene, and xylene; sulphur; and rubber copolymers. Manufactures' names, plant location, raw materials used, and finished products are included. D. W. F.

2358. Progress in petrochemicals. N. Neuhaus and N. B. Sommer. *Petrol. Process.*, May 1952, **7** (5), 641–6. (*Amer. Assn. for Advancement of Science, Philadelphia*, 30.12.51.)—A general picture is given of the petrochemical industry in the U.S. The size of the industry is estimated in terms of capital investment and sales value, together with the probable rate of expansion over the next decade. The bulk of future expansion is expected to be made by chemical firms rather than the oil industry.

The raw materials methane, ethane–ethylene, propane–propylene, butane–butylene, and aromatics are discussed in turn, their main derived products shown diagrammatically, and uses mentioned. Some quantity production data are given for the chemicals produced in the Brownsville, Texas Hydrocol plant in which methane is used as the source of synthesis gas. Many of the new synthetic fibres, plastics, and detergents are mentioned. A brief note is also made of a few miscellaneous chemicals such as the halogenated petroleum hydrocarbons. D. W. F.

2359. Petrochemical patriarch. Anon. *Petrol. Process.*, May 1952, **7** (5), 652–3.—The first plant to produce chemicals from natural gas was built in 1926 at what is now the Tallant, Oklahoma plant of Cities Service Oil Co. In an attempt to remove oxygen from natural gas, which was causing corrosion in the pipelines, high temp oxidation of the gas over a catalyst was tried. In the condensed products methanol, formaldehyde, and smaller quantities of other oxygenated compounds were found, as a result of which the Tallant plant was built. Since then it has been considerably enlarged and further facilities for separation of pure chemicals installed. D. W. F.

2360. First Udex unit recovers benzene. D. P. Thornton. *Petrol. Process.*, May 1952, **7** (4), 498–501.—A brief description without details is given of the Udex solvent extraction plant under construction at No. 2 plant Eastern States Petroleum Co., Houston, and of the platforming unit with which it will operate in conjunction. The latter unit, operating on a naphthene rich charge will supply the Udex unit with a charge containing 25% benzene, 99% of which is expected to be extracted, plus higher aromatics. Design feed to Udex plant is 1000 b.d. Solvent to be used is aqueous "glycol," probably diethylene glycol, which has high selectivity and range and good solubility for aromatics. Stabilized platformate is dehexanized in Udex feed preparation tower. Extraction tower is run with extract reflux. D. W. F.

2361. Fertilizer from refinery wastes. C. G. Bragg. *Petrol. Process.*, May 1952, **7** (4), 502–5.—By reacting waste acid-sludge with an ammonia and H_2S fouled steam, 10 tons/day of fertilizer-grade ammonium sulphate are being produced at the Torrance, California, refinery of General Petroleum Corpn. This successfully reduces atm pollution, whilst recovering usable fuel oil from the sludge and H_2S for sulphur production from the fouled steam. The sludge contains about 41% wt H_2SO_4, 14% wt water, 45% wt oil. Foul steam contains 2% of both NH_3 and H_2S. The steam is blown through the sludge in a reactor vessel, oil separated from the resulting sulphate liquor, liquor concentrated, and sulphate crystallized and centrifuged. A flow sheet is included. D. W. F.

2362. Mechanism studies on Fischer–Tropsch synthesis. P. H. Emmett and J. T. Kummer. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 15–24.—Tracer experiments using Fe_2C^{14} lead to the conclusion that most of the hydrocarbon synthesis over iron and cobalt catalysts does not occur through the formation of metallic carbides as intermediates. Adsorption experiments show that carbides by themselves are not good catalysts.

Radioactive methane in concentration up to 50% showed that fewer than 0·1% of the carbon atoms came from the methane. Radioactive oxygenated compounds are recommended as tools for investigation of Fischer–Tropsch synthesis. Results from two such experiments with ethyl alcohol show that it is connected with the synthesis as an intermediate or in a complex. D. H.

2363. A study of Fischer–Tropsch synthesis using fluidized iron catalysts. C. C. Hall and J. Rennie. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 25–37.—A sintered iron catalyst of composition 100 Fe : 1·5 K_2O prepared from steel rolling-mill scale, and a fused iron catalyst prepared for ammonia synthesis have been employed for hydrocarbon synthesis at 300 p.s.i.g. and 300° to 330° C in a fluid-bed reactor 1 inch in dia.

The fused catalyst was slightly less active and gives more methane and less liquid hydrocarbons and oxygenated products. The liquid products were of lower boiling range; carbon formation was lower.

Carbon formation was found to cause rapid expansion of the catalyst with decrease in bulk density and particle size. Its activity per unit weight was increased, thus compensating for loss by entrainment.

Data are also given of experiments on recirculation of tail gas containing C_3 to C_4 hydrocarbons. D. H.

2364. U.S. Bureau of Mines Fischer–Tropsch pilot plant studies of oil circulation processes. H. E. Benson, J. H. Crowell, J. H. Field, and H. H. Storch. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 38–56.—Results are presented from a development of the oil recycle process using fluidized catalyst. Details of the induction and synthesis operations, operating data, analyses of liquid and gas streams, calculated yield, and a typical product composition are given for several experiments. Calculated yield of gasoline and diesel products resulting from thermal and catalytic cracking of heavy distillate and wax are given, as well as characterization of the gasoline and diesel oil. D. H.

2365. Preparation of light olefins from petroleum. A. Guillemin, A. Giraud, and J. Demester. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 184–90. (In French.)—The production of olefins for Oxo synthesis of light alcohols is reviewed. Fractionation of gasolines from shale oil refining or naphtha reforming can provide low-cost olefins.

The cracking of paraffin waxes at high space velocities, low once-through yield, with steam injection also provides an economic source of olefins. D. H.

2366. Catalytic aromatization of paraffin hydrocarbons. A. Guillemin. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 244–53.—The experimental plants used by the Institute française du Pétrole are described. The pilot plant is a combined unit treating up to 10 litres/hr with a fluidized molybdena–alumina catalyst, as well as the refining redistillation of the aromatic products.

More coke is produced in the pilot plant at the expense of liquid hydrocarbon and gas when running the 75° to 150° C cut of Iraq crude. A more aromatic stock, St Marcet, gave products similar to those from the laboratory test. D. H.

2367. New SO_2 aromatic extraction unit being installed by Conoco at Lake Charles. F. L. Resen. *Oil Gas J.*, 16.6.52, **51** (6), 313.—Continental Oil Co.'s new plant is designed for 3570 b.d., removing the aromatics from a platformate and then in following sequences to selectively separate aromatics in splitter towers.

Sulphur dioxide is main extraction agent; a closed system for SO_2 recovery will be employed. G. A. C.

2368. West Texas' first sulphur-recovery unit. H. H. Jones and R. A. Graff. *Oil Gas J.*, 21.4.52, **50** (50), 122; *Petrol. Process.*, May 1952, **7** (5), 649–59.—The S. Richardson Carbon and Odessa Natural Gasoline Co.'s 20 ton/day sulphur recovery unit, employing a modified Claus process to convert H_2S in waste acid gas from amine-treating unit to eliminate sulphur is described. Entire plant operation is completely automatic, and with exception of catalysts support screen is constructed of carbon steel material. G. A. C.

2369. Naphthenates from spent caustic. M. R. Beychok. *Petrol. Process.*, May 1952, **7** (5), 656–7.—In view of the demand for naphthenic acids an economic basis is presented for studying the advisability of caustic washing distillate oils in refineries where this is not the normal procedure. The market value of the spent caustic depends upon the free acid content and the ASTM acid No. of the recoverable free acids. A suggested process line diagram is included for caustic washing distillate oils together with a lab procedure for determining the naphthenic acid content of spent caustics. D. W. F.

2370. The Elektrion process. M. Roegiers. *Petroleum*, July 1952, **15** (7), 179–85.—An account describing the history and mechanism of Elektrionization and its important

effects on lubricating oils. It is possible to Elektrionize lubricating oils by two methods :—

1. Direct Elektrionization, which comprises the simultaneous and complete treatment of the oil mols by bombardment of electrons and protons.
2. Elektrionization by blending, which consists of adding concentrated Elektrion oil which has been ultra-Elektrionized to a suitable mineral oil.

Elektrionization increases the visc and V.I. of the oil; improves the oiliness and colour; lowers the pour point and Conradson Carbon Test figures; improves oil resistance to sludge formation and develops "peptizing properties" towards carbon black or other finely divided combustion products and towards the eventual insoluble oxidation products of the oil.

Elektrion oils give stable homogeneous mixtures with all kinds of motor oil except castor oil, whether straight mineral oils or "doped" with organic metallic additives.

R. E. P.

2371. Patents. U.S.P. 2,583,611 (13.7.46; 29.1.52). F. W. Sullivan, assr to Hydrocarbon Research Inc. The catalytic hydrogenation of carbon oxides to give hydrocarbons and oxygenated hydrocarbons wherein synthesis gas containing in suspension relatively fine adsorbent particles capable of adsorbing the liquid products of the reaction is passed through a dense, fluidized catalyst bed.

U.S.P. 2,583,619 (15.3.44; 29.1.52). P. C. White, assr to Standard Oil Co. Producing a Raney catalyst surface on the interior of a conversion chamber by forming thereon an alloy layer consisting of iron, cobalt, or nickel, or mixtures thereof alloyed with 35 to 65% of silicon, aluminium, or zinc, leaching the alloy layer with an aqueous solvent to remove the alloying metal and activating the residual skeleton layer of catalyst metal by hydrogen treatment.

U.S.P. 2,583,729 (28.11.47; 29.1.52). R. M. Deanesly, assr to Universal Oil Products Company. Recovering a Schiff's base from a ketone/aldehyde—primary amine reaction mixture containing water without appreciable hydrolysis of said Schiff's base by contacting the mixture first with a solid dehydrating agent, thereafter with anhydrous ammonia, and finally with further dehydrating agent.

R. C. R.

2372. Patents. U.S.P. 2,584,269 (25.10.48; 5.2.52). L. P. Hodges, assr to Standard Oil Development Co. Oxygenated organic compounds are removed from naphtha obtained by synthesis from carbon monoxide and hydrogen over an iron catalyst, by mixing the naphtha with a hydrocarbon lubricating oil, an alkali metal naphthenate, and an alkali metal hydroxide, subjecting the mixture to distillation and recovering from the distillation a gasoline fraction free from oxygenated organic compounds.

U.S.P. 2,585,033 (23.12.46; 12.2.52). E. W. Pitzer, assr to Phillips Petroleum Co. Spent catalyst, which has been used for dehydrogenating paraffins and which consists of a difficultly reducible heavy metal oxide on a carrier, is reactivated by grinding, digesting the ground catalyst with conc nitric acid, evaporating to dryness, heating to decompose the nitrate, regrinding, mixing with a volatile organic binder, shaping, and igniting to remove the binder.

U.S.P. 2,585,659 (25.3.46; 12.2.52). M. O. Kilpatrick, assr to Phillips Petroleum Co. Carbon black is recovered from suspension in a gas by scrubbing the gas with an aqueous liquid containing a wetting agent and recycling part of the resulting aqueous slurry of carbon black to the gas scrubbing operation.

U.S.P. 2,585,737 (21.10.48; 12.2.52). C. Le Roy Carpenter, assr to Standard Oil Development Co. A gaseous mixture of carbon monoxide and hydrogen is made by passing a normally gaseous hydrocarbon and an oxidizing gas containing steam over a Group VIII metal at 1300° to 2000° F, a further portion of hydrocarbon being injected into the reactor downstream from the point of entry of the main reactants.

U.S.P. 2,585,981 (23.11.45; 19.2.52). C. W. Watson, assr to The Texas Co. Hydrocarbons and oxygenated hydrocarbons are made by passing a mixture of carbon monoxide, hydrogen, water vapour, and carbon dioxide through a reaction chamber containing fluidized particles of iron at 550° to 700° F. The molar ratio of hydrogen to carbon monoxide is at least 2 : 1, the amount of water vapour is not more than corre-

sponds to saturation at 100° F, and the proportion of carbon dioxide is sufficient to suppress the water-gas reaction between the carbon monoxide and water vapour to yield carbon dioxide.

U.S.P. 2,586,341 (4.10.50; 19.2.52). A. M. Hyson, assr to E.I. du Pont de Nemours and Co. Trans-3-pentenoic acid is made by heating at 100° to 250° C and under a pressure of at least 700 atm butadiene, carbon monoxide, and water in presence of dimethylformamide or dimethylacetamide and a cobalt carbonyl catalyst.

U.S.P. 2,586,377 (31.12.47; 19.2.52). E. W. Pitzer, assr to Phillips Petroleum Co. Hydrocarbons having from 2 to 10 carbon atoms are dehydrogenated by subjecting them at 900° to 1300° F under a pressure up to 500 p.s.i. at a flow rate of 0·5 to 5 liquid vols of feed per vol of catalyst per hr to contact with a synthetic gel catalyst of alumina and an oxide of vanadium, chromium, molybdenum, or tungsten. The manufacture of the catalyst is described.

U.S.P. 2,586,618 (8.11.46; 19.2.52). J. C. Dart, assr to Standard Oil Development Co. In the synthesis of hydrocarbons from carbon monoxide and hydrogen in presence of an iron, cobalt, or nickel catalyst, a stream is withdrawn from the reaction zone at a point between the feed inlet and the product exit, cooled to remove water, treated to remove carbon dioxide, and returned to the reaction zone.

U.S.P. 2,586,929 (18.4.49; 26.2.52). H. W. Fleming and J. S. Cromeans, assrs to Phillips Petroleum Co. Reaction products from the hydrogenation of a carbon oxide are separated into a hydrocarbon and an aqueous phase. Products boiling below 77° C are distilled from the aqueous phase, and an azeotrope of methyl-*n*-propyl ketone, ethyl alcohol, and water is then removed. The ethyl alcohol in the azeotrope is esterified with formic or acetic acid and the ester and ketone recovered by distillation.

U.S.P. 2,587,107 (5.12.49; 26.2.52). G. N. Cade, assr to Phillips Petroleum Co. Carbon black is produced by pyrochemical cracking of hydrocarbons to produce carbon black containing tar, extracting the tar from the carbon black with a chlorinated hydrocarbon solvent of 1 to 3 carbon atoms, recycling part of the solvent in the extraction stage, passing the rest of the solvent and tar to the pyrochemical cracking stage, and recycling part of the hydrogen chloride formed in that stage. J. M. S.

2373. Patents. Ger.P. 829,295, 20.12.51. Standard Oil Development Co. Procedure for selective separation of *iso*butylene from hydrocarbons.

Ger.P. 831,393, 10.1.52. H. Weghofer, assr to Krupp Treibstoffwerk. Process for nitration of saturated, non-aromatic hydrocarbons.

Ger.P. 829,593, 27.12.51. E. Keunecke and K.-H. Imhausen, assrs to Imhausen & Co. Process for catalytic oxidation of higher molecular aliphatic hydrocarbons.

Ger.P. 827,063, 29.11.51. W. Münster, assr to Bad. Anilin- & Soda-Fabr. Process for production of ethylene.

Ger.P. 831,996, 17.1.52. H. Noeske, assr to Ruhrchemie A.-G. Method for producing primary amino paraffins.

Ger.P. 827,803, 6.12.51. L. Weschky, assr to Bad. Anilin- & Soda-Fabr. Method for producing methyl ethers of dihydroxybenzenes.

Ger.P. 832,312, 24.1.52. A. Gislon and J. Quiquerez, assrs to Comp. Franç de Raffinage. Procedure for refining petroleum products. (Prior. France 26.8.49.)

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Metering and Control

2374. Precision volumetric meters. P. Sery, L. Krach, and M. de la Chapelle. *Proc. 3rd World Petrol. Congr.*, 1951, **9**, 125. (In French.)—The article is comprised of three papers dealing with: (*a*) the tendencies in the French petroleum industry regarding the use of volumetric meters; (*b*) the accuracy of volumetric meters; and (*c*) the use of volumetric meters in measurement of tank cars.

At present the use of volumetric meters in France is tending to grow, it is general for highway distributors and for the execution of certain measurement work, *i.e.*, measure-

ment of tank cars. This type of meter is likely to be used for the Le Havre–Paris pipeline, and will probably be extended to the refineries and depots if the meters are sufficiently accurate in use, precise, and robust. The packed sealed meters are suitable for retail distribution. Capillary sealed meters, with greater precision, are more suitable for great yields and for continuous functioning. D. K.

2375. A new technique : instrumentation of a fluid catalytic cracking unit. D. J. Bergman. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 523–38.—A background to the process and operating conditions of a fluid catalytic cracking unit. The plant and flow diagram are described and illustrated.

The controls and operating variables are discussed.

Trends in the use of miniature graphic meter panels are indicated. D. H.

2376. Some new measurement and control devices. D. J. Pompeo, J. Parker, and S. S. Smith. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 506–22.—Increasing application in industry is noted for the instruments described. A continuous recording titrimeter for measuring mercaptans in gasoline, a dielectric constant recorder for water content of ketones, a recording viscometer for lub oil applications, a method of controlling centrifugal filters used to separate a slurry into solid and liquid components are described in construction and operation.

Details are given of a mechanism for monitoring and controlling pipeline stations by teletype from a remote central point. D. H.

2377. Economics of instrumentation in petroleum refining. A. M. Platt and G. L. Farrar. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 488–93.—The choice between qualitative indicators, quantitative indicators, and recorders is viewed from the economic angle. Data from many plants (several examples given) indicate that installed instrument cost should be 5% of the total investment, and maintenance equipment cost should be about 0·1% of the total investment. D. H.

2378. Engineering fundamentals. R. F. Nielson. *Oil Gas J.*, 30.6.52, **51** (8), 190.—No. 486 in this series deals with measurement of gas flow by means of venturi and orifice meters; equations being evolved for use with these meters. G. A. C.

2379. Metering vs gauging. O. M. Turner. *Oil Gas J.*, 23.6.52, **51** (7), 65.—Factors in economic comparison of product measurement methods are considered, and figures quoted to show case for installation of meters. G. A. C.

2380. How to use 3-way control valves. J. A. Pellettere and R. L. Patton. *Petrol. Process.*, Apr. 1952, **7** (4), 480–5.—Three-way control valves are described, and their use as stream-diverting or mixing valves discussed with particular reference to by-pass control of heat exchange equipment. Diagrams of two types of valves, double seated and single seated valve bodies, are given. Flow layout and valve-type selection are considered in relation to pressure drop across the valve. A chart is included correlating pressure drops with flow rates at varying percentages of by-pass together with a sample calculation to illustrate the use of this chart. D. W. F.

2381. Some aspects of cascade and multi-element control systems. J. C. Farquhar. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 494–505.—The principles of compound control are explained with five typical flow diagrams. The conclusions are that independent controllers should be used to eliminate disturbances in factors which have no relationship to plant load, *e.g.*, process steam pressure, fuel gas supply pressure. Cascade control should be used where it is necessary to eliminate errors due to control valve or damper characteristics and system flow and pressure drop relationships. For close analytical control or for varying loads, compound control should be used to establish relationships between physical quantities or conditions which should bear relationships to each other and to the plant load. An overriding control can adjust the whole system to the desired level.

The balancing of disturbance lags is discussed. D. H.

2382. Measurement of air pollution. H. J. van Ebbenhorst Tenbergen. *Ingenieur*, 27.6.52, **64** (26), G62–8.—Air pollution in plant neighbourhood is generally measured by a wide range of apparatus. In comparative tests, carried out near a coke- and nitrogen-fixation plant, widely varying results were obtained. Still the measurements with vaseline-covered spheres and SO_3-meters gave a valuable idea of the air pollution in this area. G. F. T. C.

2383. Patent. U.S.P. 2,584,083 (22.2.45; 29.1.52). D. S. Mellett, assr to Socony-Vacuum Oil Company. An improved gate valve. R. C. R.

PRODUCTS

Chemistry and Physics

2384. Compilation of data on the properties of hydrocarbons and related compounds. F. D. Rossini. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 157–239.—A survey is given of the activities of API Research Project 44, which collects, analyses, calculates, and compiles data on physical thermodynamic and spectral properties of hydrocarbons and related compounds. The indexes to these properties are reproduced in full, together with an example of the extent of the data available and their source. D. H.

2385. The Hydrocarbon Research Group of the Institute of Petroleum, its development and functions. D. W. Bradford. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 240–6.—The group operates by supporting fundamental research work at universities in various ways. Its activities include spectroscopy, the study of hydrocarbon synthesis and hydrocarbon reactions and mass spectrometry. No permanent research projects are undertaken, and the aim is to maintain an adaptable organization which will permit the direction of efforts to be expanded or changed from time to time in accordance with current needs. (Author's Abstract.) D. H.

2386. The synthesis, purification and properties of hydrocarbons of low molecular weight. C. E. Boord. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 247–58.—The API Research Project 45 covers the synthesis, purification, and properties of hydrocarbons; engine testing; and preparation for superpurification and measurement of physical constants.

Quantities up to 1 gal were synthesized and purified by hydrogenation of one or more of the unsaturated hydrocarbons having the desired carbon skeleton. The scheme of synthesis is set out in detail for pentanes, hexanes, heptanes, octanes, pentenes, and hexenes, including all structural and geometric isomers. Others were prepared by Grignard reagents and other special methods. D. H.

2387. Hydrocarbon syntheses in the *cyclo*butane series. II. 1-methyl-3-ethyl*cyclo*butane and di-(3-methyl*cyclo*butyl)-methane. B. A. Kazanskii and M. Yu. Lukina. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1952, 314–22. (*Cf.* Abs. No. 1453—1951.)—Starting material for both syntheses was 1-methyl*cyclo*butane-3-carboxylic acid. Proceeding through 1-methyl-3-acetyl*cyclo*butane there was obtained 1-methyl-3-ethyl*cyclo*butane which by fract on fifty-plate-column was separated into *trans* (b.p. 87·9° to 88·1° C, n_D^{20} 1·4005, d_4^{20} 0·7224, an. pt. 57·2° C) and *cis* (b.p. 91·0° to 91·1° C, n_D^{20} 1·4043, d_4^{20} 0·7316, an. pt. 52·2° C) forms. Through di-(3-methyl*cyclo*butyl)-ketone there was obtained di-(3-methyl*cyclo*butyl)-methane (b.p. 178° to 184° C (747 mm), n_D^{20} 1·4402, d_4^{20} 0·8027); separation into isomers was not possible owing to small quantity available. Increments over the calc values of mol refractivity for *cyclo*butane derivatives previously reported in the literature are discussed, the mean value (approx 0·48) is less than that for the *cyclo*butane compounds prepared in the present series (0·60); increase is considered to be due to existence of di-substituted *cyclo*butanes in *cis–trans* forms, the latter having higher values of mol refractivity. V. B.

2388. Isomerism of the constituents of petroleum. M. Bestougeff. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 11–20. (In French.)—The isomerism of the petroleum hydrocarbons is reviewed by examining each homologous series in succession. It is found that certain rules can be laid down for the chemical composition of petroleum and the distribution of the constituents in various fractions of one and the same kind of petroleum.

The total number of isomeric hydrocarbons of petroleum, though rather high in absolute figures, represents only a small fraction of the isomers theoretically possible.

The limitations observed for the isomerism of petroleum hydrocarbons are discussed.

The explanation of the problems resulting from the isomerism of the petroleum constituents may elucidate the question of the origin and evolution of petroleum. (Author's Abstract.) D. H.

2389. *Cyclo*pentane and neohexane in petroleum. R. F. Marschner and D. E. Burney *Industr. Engng Chem.*, 1952, **44**, 1406–8.—Describes experimental work carried out on the fractionation of naphthas to ascertain the quantities of *cyclo*pentane and neohexane present in petroleum. Data also given on azeotropes of *cyclo*pentane–neohexane, *cyclo*hexane–2 : 4-dimethylpentane and *cyclo*hexane–2 : 2 : 3-trimethylbutane. E. J. C.

2390. The viscosity of hydrocarbons. L. Grunberg and A. H. Nissan. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 279–311.—The dynamic and kinematic viscs of 321 liquid hydrocarbons are presented in tabular form at 10° intervals from 0° to 100° C. The accuracy is estimated to be better than 1%.

Bridgman's data for the visc of some liquid hydrocarbons at high pressure are given graphically. Graphical data on hydrocarbon gases at high pressures and for liquid hydrocarbons near the critical point are estimated at 10% accuracy.

Methods of estimating visc are given. From a single experimental determination and the atmospheric b.p. the whole visc–temp curve of a hydrocarbon can be calculated with 6% accuracy.

A nomograph for high pressure gases and for liquids near the critical point, and an equation for gases at 1 atm give 10% accuracy. D. H.

2391. Determining volume changes in hydrocarbon blending. E. J. Reeves. *Petrol. Process.*, Apr. 1951, **7** (4), 478–9. (*Mtng Amer. Chem. Soc. Austin, Texas, Dec.* **7**, 1951.)—Saturated hydrocarbons at low pressure and atm temp have been shown to form non-ideal solutions, vol changes occurring in blending. Within 0 to 15% vol of low mol. wt. compounds the contraction is a function of the mol. wt. of the blend components. Blending values, defined as ratio of partial sp. vol. to actual sp. vol., are given for some hydrocarbons, together with a chart permitting the estimation of blending values. Fourteen references for blending values are given. D. W. F.

2392. A contribution to the problem of estimation and interpolation of vapour pressure data of homologous compounds. H. Stage. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 27–34.—Methods for extrapolation and interpolation of vapour pressure data are described which have been used to predict data not previously available. Plotted data given include vapour pressure v temp for n-alkylhydrocarbons, and boiling temp v No. of C atoms in a group or molecule for organic series. E. J. C.

2393. Refractivity intercept and refractivity quotient of series of homologous hydrocarbons. J. Smittenberg. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 312–18.—A new function of refractive index and density, the "refractivity quotient" r.q. = $(d_\infty - d) \div (n_\infty - n)$ is developed and is claimed to be a better characteristic constant (independent of mol. wt.) for series of homologous hydrocarbons than the frequently used "refractivity intercept." (Author's Abstract.) D. H.

2394. Correlating physical thermodynamic properties used in petroleum technology. D. F. Othmer and R. Gilmont. *Proc. 3rd World Petrol. Congr.*, 1951, **3**, 1–26.—Graphical plots are presented which permit ready extrapolation and interpolation of physical data on many hydrocarbons and organic chemicals of interest in the petroleum and petrochemical field. Data covered are vapour pressure, gas solubility, gas

absorption, equilibrium vapour composition constant, chemical reaction equilibrium constant, density of liquids, visc of liquids and gases, surface tension, and entropy.
E. J. C.

2395. Vapour pressure–temperature relationships of sulphur compounds related to petroleum. P. T. White, D. G. Barnard-Smith, and F. A. Fidler. *Industr. Engng Chem.*, 1952, **44**, 1430–8.—Apparatus and method described for determining vapour pressure–temp relationships for alkane sulphides, alkane disulphides, cyclic sulphides, and thiophenes. Latent heats of vaporization were also calculated. Data are tabulated and plotted. E. J. C.

2396. Alumina–silica cracking catalyst : influence of aluminium content on activity. M. W. Tamele, L. B. Ryland, L. D. Rampino, and W. G. Schlaffer. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 98–105.—Critical study of the procedures for the preparation of alumina–silica catalysts throws considerable light on the influence of aluminium content on activity and on the nature of the active centres.

It has been shown that, under certain conditions, aluminium ions undergoing hydrolysis in presence of silica gel may, instead of forming aluminium hydroxide, become attached to silica surface by condensation with the terminal hydroxyl groups of the gel.

The most probable structure of the active centres formed by this interaction is presented and discussed. D. H.

2397. Effect of dimensions of elementary crystals on porosity and activity of Al_2O_3 catalysts in the dehydration reaction. A. M. Rubinshtein, V. E. Vasserberg, and N. A. Pribuitkova. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1952, 323–33.—Three samples of cat were prepared from alumina, pptd from the nitrate with NH_3 and classified into fractions of varying fineness by sedimentation. Main dehydration experiments were on 77·5% HCOOH and 96% C_2H_5OH, tests were also done on *n*-butanol and *n*-pentanol. Cat samples were examined by X-rays. All three cats were exclusively γ-Al_2O_3, having identical lattice parameters; greatest activity being shown by that with largest linear dimensions of crystals (51 to 52 Å). Spec area of this cat measured by *n*-pentane adsorption was 264 m^2/g, that of least active 179 m^2/g; results with CH_3OH were identical (286 m^2/g) for all three samples. Micropore dimensions of cat are determined by dimensions of the elementary crystals and mode of their aggregation into secondary particles, the cat grain. Pore dimensions should be similar to those of mol of material reacting on cat. Determination of cat area by low temp adsorption of N_2 is not satisfactory for assessing cat activity in respect of larger mols. V. B.

2398. Iron and copper catalysts in the oxidation of hydrocarbon lubricating oils. J. H. T. Brook and J. B. Matthews. *Faraday Soc. Discussions*, 1951, **10**, 298–307.—Circulatory O_2 absorption apparatus used had provision for automatic recording of O_2 uptake; volatile products were not returned to reaction vessel. Cu and Fe stearate, Cu wire, reduced Fe powder, and crankcase sludge were used as cat, activity of solid cat was found to be due to corrosion. Oxidn kinetics of a typical lub oil at 150° C were studied, reaction with sol Fe obeyed Semenov's equation $V = \frac{A}{\phi} \cdot e^{\phi t}$ at cat concn 20 to 100 p.p.m., but reaction rate fell away from the theoretical at lower concn. V = vol of O_2 absorbed, A is initial reaction rate, ϕ is net chain-branching coeff. Similar results were obtained for solid Fe. Reaction with sol Cu did not fit above equation, a max effect was obtained at 20 p.p.m., due possibly to micelle formation (mol. wt. 5000 found for 200 to 800 p.p.m. in *cyclo*hexane, whereas 1600 was found for ferric stearate in 100 to 400 p.p.m., corresponding to the dimer). Kinetic data indicate that sol Cu was a good chain-initiator and dissolved Fe a good chain-branching cat. E. B.

2399. Physico-chemical study of the large-scale production of Fe–Cu catalysts. J. Benoit and M. Quesson. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 57–67. (In French.)—The ferrous ferric catalyst precipitated in the laboratory was active, but was mediocre when precipitated industrially.

The registration and interpretation of the graphs of electrochemical and magnetic phenomena have made it possible to show the cardinal points of the precipitation. Identical investigations into catalyst reduction have also furnished interesting facts. (Author's Abstract.) D. H.

2400. Reactions of liquid ethyl benzene with oxygen in glass vessels. G. M. Henderson. *Faraday Soc. Discussions*, 1951, **10**, 291–8.—Study of oxidn of ethyl benzene at 130° C showed that the initial slow reaction is replaced by a faster wall-catalysed reaction, both producing hydroperoxide only. Rate of formation of hydroperoxide depended on vol of the charge, irrespective of whether pure ethyl benzene or mixture containing up to 33% diphenyl was used. Steady rate, once established, was unaffected by increase in vol, but increased when the vol was reduced. Variation in air flow, bubble size, and pO_2 did not alter established rate. Evidence was obtained indicating that resonance-stabilized free radicals were deposited on the vessel walls. Special cleaning was required before the walls were entirely deactivated, hot HNO_3 or HNO_3/HCl mixtures were satisfactory, but cleaning with organic solvents, water, and then baking for brief periods was inadequate. E. B.

2401. Separation and chemical identification of the constituents of residues and bitumens. M. Bestougeff. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 116–30. (In French.)—By systematic application of fractionation by mol distillation, adsorption, and selective extraction, heavy residues have been separated into a large number of fractions.

A basis of chemical classification according to families and very different classes of bodies, such as organo-metallic compounds, has been made.

An attempt has been made to establish the type of bonds of carbon atoms in the polycyclic molecules of resins and asphaltenes.

In the light of these studies one may assume that certain constituents of natural resins and asphaltenes have been formed from simpler molecules with the aid of the hetero-atoms present in the matter itself or introduced from outside by other substances. (Author's Abstract.) D. H.

2402. Study of the composition of Middle East crude fractions. L. Robert, J. Boucheny, and E. J. Favre. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 53–67. (In French.)—The distribution of different hydrocarbons and classes of hydrocarbons has been studied in the fractions of a Middle East crude (Aramco). A light gasoline and a gas oil were fractionated by analytical distillation under atmospheric pressure and vacuum respectively. Light and medium distillates of the heavy fractions were obtained by distillation under cathode vacuum. The compositions of the fractions have been established by several methods, *e.g.*, refractive index, density, aniline point, specific refraction, infra-red, ultra-violet, and mass spectra, and separation by selective adsorption on silica gel. (Author's Abstract.) D. H.

2403. The properties of Venezuelan crude oils. W. L. Nelson, J. Martorano, and G. T. Fombona. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 336–44.—Data on the properties of fifteen major crudes cover the gravity, sulphur, characterization, and yields of the following products: gasolines, jet fuel, kerosine, diesel, cracking stock, untreated lube, and asphalt and their qualities. The average and exceptional properties of refined products are summarized. D. H.

2404. Classification and evaluation of crude oils. K. W. Schneider. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 345–52.—A method of classifying crude oils is described covering, in the case of paraffinic oils, up to 92% of the oil ingredients without applying strong heating. The distillate to 280° C is subject to group-analysis in two fractions, and the residue is separated by chromatography into two fractions. The proportion of paraffins in the colourless fraction is found graphically from the refractive index. The asphalts may also be examined if required.

The method is said to give a better index of the potential qualities of refined products. The usual determinations of physical properties of fractions have to be made for design purposes. D. H.

2405. The nature of soap thickened lubricating greases. M. J. Vold and R. D. Vold. *J. Inst. Petrol.*, 1952, **38**, 155–63.—Phase diagrams have been determined for calcium stearate and its hydrate, and lithium stearate, in cetane and decalin, and the system

sodium stearate–cetane. Grease systems of apparently similar phase condition may differ from each other in physical behaviour, and this is attributed to the existence of a definite type of " structure " of the dispersed soap particles. A. R. W. B.

2406. The deterioration of transformer oil. Pt I. Operating difficulties and their causes ; Pt II. Influence of transformer constructional materials. L. Massey. *J. Inst. Petrol.*, 1952, **38**, 164–71 ; 281–97.—The factors influencing the use of oil in a transformer are discussed and operating conditions described in Pt I. The effects of oxygen and moisture upon oil breakdown are related to the practical evidence which they produce, and requirements for limiting oil breakdown are discussed.

In Pt II experiments to assess the influence of transformer constructional materials, of an accelerated type and also under conditions approximating to transformer practice, are described. Copper is shown to be much more active than any other single material, and the factors affecting this activity have been studied. Thin films of varnish used to protect exposed metal surfaces are shown to be inert towards oil and to form effective barriers, isolating the metal from contact with oil. A. R. W. B.

2407. Studies in shale oil. Pt II. Some water soluble constituents. Pt III. Some constituents of shale naphtha. G. E. Mapstone. *J. Inst. Petrol.*, 1952, **38**, 98–107 ; 172–7.—Various classes of organic compounds were found to be present in the aqueous liquors from the crude oil separators at Glen Davis. The methods by which they were detected are recorded and the results discussed in Pt I.

Among the minor constituents of Glen Davis shale naphtha, benzene, naphthalene, and carbon disulphide were isolated. Qualitative proof of the presence of several other hydrocarbons, phenols, sulphur and nitrogen compounds is reported in Pt II. A. R. W. B.

2408. Studies in shale oil. Pt IV. The sulphochlorination of a selected shale oil fraction. G. Nottes and G. E. Mapstone. *J. Inst. Petrol.*, 1952, **38**, 178–9.—An olefin- and aromatic-free fraction of shale oil of sp. gr. 0·800 was sulpho-chlorinated by means of the Reed reaction under the influence of the light of a tungsten-filament lamp. A. R. W. B.

2409. Studies in shale oil. Pt V. Aldehyde resins from shale tar bases. Pt VI. A note on the discoloration of cracked shale gasoline. G. E. Mapstone. *J. Inst. Petrol.*, 1952, **38**, 180–91 ; 192.—Shale-tar bases may be condensed with formaldehyde in acid solution to give acid insoluble resins, and also under suitable conditions with phenol. Two possible mechanisms whereby these resins might be formed are discussed, and details of the experimental work carried out are given.

In Pt VI it is suggested that the brownish-red discoloration formed in this gasoline is partly due to the formation of some quinones by oxidation, and the association of these quinones with the pyridine homologues present. A. R. W. B.

2410. The physico-chemical properties of bitumen. R. Darmois. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 140–56. (In French.)—This study shows that the colloidal state of bitumens is conditioned at ordinary temp not only by the nature of its parts, but also, and to an extent no less important, by the temp, of which no wide variation is necessary (from 20° to 50° C) to bring about a complete change in the collodial state.

It is probable that this change of physical state with the temp will show in very different ways, according to the origin and the treatment of the bitumen, considering the great chemical and physical variety of the substances included under the name of bitumens. (Author's Abstract.) D. H.

2411. Spreading of liquids on low energy surfaces. IV. Monolayer coating on platinum. E. G. Shagrin and W. A. Zisman. *J. Coll. Sci.*, 1952, **7**, 166–77.—The equilibrium contact angle (θ) has been measured for a Pt surface covered with a monolayer of *n*-octadecylamine and some sixty liquids, including water, *n*-alkanes, *cyclo*alkanes, *n*-alkyl benzenes, di(*n*-alkyl) ethers, fluorocarbons, esters, etc. Measurements were made in triplicate at 20° C and R.H. = 50% with a goniometer, and three different methods were employed to form and measure the sessile drops.

For every homologous series a linear relation was found between cos θ and surface

tension ; all liquids fell on one of three straight lines. Similar sets of three curves were found on plotting surface tension against work of adhesion or spreading coefficient, and this grouping corresponds to the difference in solid/liquid interfacial tension and to the solvent effect of the liquids on octadecylamine. Constant values of free energy decrease on immersion (f) were observed for the homologous n-alkanes and n-alkyl ethers ; the alkyl benzenes showed a linear decrease with increasing surface tension.

It is concluded that the wetting behaviour of a surface is essentially controlled by the nature and packing of the outermost group of atoms in the adsorbed molecule.

H. C. E.

2412. Spreading of liquids on low energy surfaces. II. Modified tetrafluoroethylene polymers. H. W. Fox and W. A. Zisman. *J. Coll. Sci.*, 1952, **7**, 109–21.—Equilibrium contact angles of water, n-alkanes, di(n-alkyl) ethers, and other organic compounds on prepared surfaces of halogenated polyethylene derivatives have been measured, and the free energy decrease of immersion (f), the work of adhesion (W_A), and the spreading coeff have been calc for the liquids which do not spread. For each solid surface the contact angle and spreading coeff of the liquid increase and decrease respectively as the surface tension of the liquid increases. For n-alkanes and di(alkyl) ethers a plot of surface tension *versus* W_A or spreading coeff gives straight lines with slopes of $+45°$ and $-45°$ respectively.

As Cl_2 or H_2 is substituted for F_2 in the solid polymers, W_A, f, and spreading coeff increase in amount dependent on the amount of substitution. H_2 gives a smaller increase than Cl_2. In general, f is prop to mole-% of fluorine substitution.

The idea that non-polar liquids wet non-polar solids does not appear to be well-founded. It is shown that attempts to measure the surface tension of solids by contact angle measurements alone involve unjustifiable assumptions. H. C. E.

2413. Process of spontaneous emulsification. M. van der Waarden. *J. Coll. Sci.*, 1952, **7**, 140–50.—Emulsions were formed by pouring into water, with moderate stirring, solutions of sodium alkylbenzenesulphonates (R = 12, 16, and 20 to 22 carbon atoms) in a white mineral oil of measured composition ; or by adding water to the hydrocarbon solution until phase inversion occurred. The surface tension of the emulsions, determined on a du Nouy tensiometer, was used as a measure of the sulphonate concentration in the water phase.

It was found that part of the sulphonate passes into the water phase and that the adsorption equilibrium is established between the sulphonate in the water phase and that in the interfacial layers of the oil droplets. Plots of sulphonate in the oil phase *v* sulphonate in the water phase gave curves resembling the normal adsorption isotherms.

A probable mechanism for the process of spontaneous emulsification is discussed.

H. C. E.

2414. Influence of surface films on the friction of solid materials. E. P. Bowden. *Schweiz. Arch. Ang. Wiss. Tech.*, 1952, **18**, 116–27.—Lecture describing recent work carried out at Cambridge. Very high coeff of friction (μ up to 100) is shown by metal/metal (*e.g.*, Fe) in vac ; μ falls on access of traces of O_2, H_2, H_2O (reversible effect), caproic acid, H_2S, Cl. Similar effects are observed for diamond, carbon, and graphite ; traces of O_2 and H_2O decreasing μ. Diamond/diamond friction does not obey Amonton's law. Protective effect of oxide films is mainly linked with the hardness of the film ; relative atomic lattice dimensions of the metal and of the oxide are of less significance. Friction of steel on Al follows Amonton's law over a load range varying by 10^6, friction of Cu on Cu varies with load (at small loads) due to similar hardness of the metal and oxide, the film of the latter following the deformation of the metal. Under boundary lubrication conditions mere physical adsorption of the lubricant does not suffice to provide complete protection, chemical reaction between the metal and the lubricant being required. μ is higher for adsorbed films than for combined films (*e.g.*, fatty acid soaps) as shown by comparative experiments on inert (Au, Pt) metals and others, supporting evidence is break in friction/temp curve occurring at m.p. of soap, and not at lower temp of m.p. of fatty acid. A further break also occurs at temp corresponding to desorption of lubricant film or of vaporization. Studies on friction of plastics have shown higher μ for materials containing branched chains (*e.g.*, poly-

methylmethacrylate) than for straight chains (*e.g.*, polyethylene). Exceptionally low μ (0·04) is shown by polytetrafluorethylene (Teflon). Physical properties of Teflon are not suitable for a constructional material, but promising results have been obtained by sintered Cu impregnated with Teflon. Low μ, especially at high temp (400° C), have also been obtained with sintered Mo converted to MoS. V. B.

2415. A contribution to the theory of the development and stability of detonation in gases. A. K. Oppenheim. *J. appl. Mech.*, 1952, **19**, 63.—The development of detonation of an explosive gas mixture contained in a constant-cross-section duct is analysed on the basis of a double-discontinuity combustion system. A steady and an unsteady system are considered, and it is shown that the latter yields an adequate explanation of the effect of coalition of the two discontinuities on the establishment and subsequent stability of the detonation wave. The locus of states behind the detonating combustion zone during the development of the process is determined and analysed. (Author's Abstract.) L. G. H.

2416. Differential method for the kinetic study of gas phase reactions. E. Freling and P. Dugleux. *Rev. Inst. franç. Pétrole*, 1952, **7**, 103–5.—Experimental note describing a thermally compensated pressure gauge for following oxidn reactions by a static method. Valve admitting mixture simultaneously to test cell and manometer and at the same time controlling gas admission to compensating cell and outer space of differential manometer is mechanically operated. Layout is illustrated and constructional details given. Mirror-reading gauge has sensitivity of 10 mm scale deviation for 1 mm Hg pressure. V. B.

2417. Study of solid paraffins by physical methods. L. Robert, C. Alexanian, and J. Buzon. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 259–78.—A statistical study of data from X-rays, electron diffraction, infra-red spectrometry, electron microscopy, and physico-chemical constants is presented to permit characterization of solid paraffins and to determine the crystalline parameters of normal paraffins. A second part is devoted to the application of these methods to the study of solid paraffin fractions prepared from a commercial vaseline. (Authors' Abstract.) D. H.

2418. Time required for constant-volume combustion. A. S. Campbell. *J. appl. Mech.*, 1952, **19**, 73.—By combining the results of an elementary thermodynamic analysis of the temp distribution in the burned gases of a constant-vol bomb with an examination of the velocity relations at the flame front, it is possible to relate the "normal burning velocity" to the time rate of production of burned gases. Integration of this equation leads to an estimate of the time required for the combustion process. (Author's Abstract.) L. G. H.

2419. Flame propagation in cylindrical tubes. P. Levine. *Mech. Engng*, June 1952, **74** (6), 483.—An experimental study of flame characteristics indicates that flame propagation is influenced by the size, shape, and position of combustion chamber. The fuel used was propane premixed with air. Details of apparatus and procedure are given. The flame shape observed in all tests was a distorted semi-elliptical form, and the reasons for this are discussed. Results showed that the propagation velocity varied with air–fuel ratio, the max velocity occurring with a mixture richer than stoichiometric. With air–fuel ratios above 20 : 1 and below 6 : 1, the mixture would not support flame propagation. Flame velocities increased with increase of tube dia, and the max velocity occurred with the tube vertical and the flame travelling upwards. Five references. T. T.

2420. Patents. Ger.P. 830,940, 10.1.52. G. Muth, assr to Metallgesellsch. A.-G. Device for preferable electrical dust removal from gases containing inflammable dust.

Ger.P. 831,544, 17.1.52. P. Schmalfeld, assr to Metallgesellsch. A.-G. Procedure and apparatus for activation of materials containing carbon.

Ger.P. 829,887, 27.12.51. R. Rössler, assr to German Solvay-Werke. Process for chlorination of naphthalene.

Ger.P. 827,064, 29.11.51. W. Oettinger and H. Nonnenmacher, assrs to Bad. Anilin- & Soda-Fabr. Procedure for production of gaseous unsaturated hydrocarbons. (Addn. to No. 818,346.)

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Analysis and Testing

2421. Research and development at Fulmer Hall. Anon. *Petrol. Times*, 11.7.52, **56**, 578.—A brief description of the research laboratories belonging to Monsanto Chemicals Ltd., at Fulmer Hall, Bucks, and their activities. G. A. C.

2422. Spectrometric methods of petroleum analysis. R. R. Brattain, L. C. Jones, and T. P. Weir. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 81–93.—Analytical methods, based upon the interaction between electromagnetic energy and molecules or atoms, are compared, and examples are given of their application to petroleum research. The similarity between X-ray, ultra-violet, infra-red, visible, emission, Raman, and mass spectrometry and their limitations are emphasized. D. H.

2423. Analytical mass spectrometry in the petroleum industry. W. S. Young, R. A. Brown, and F. W. Melpolder. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 94–104.—Progress made since 1942 is reviewed. The accuracy attainable on mixtures of hydrocarbons from petroleum and its processing and on mixtures from other chemical industries is illustrated by typical results.

Analysis of heavy hydrocarbons and waxes is difficult. A heated inlet system is detailed which has been used to determine paraffins; *cyclo*paraffins and mono-olefins; decalins and acenaphthalenes; alkylbenzenes, tetralins, and phenyl*cyclo*paraffins; naphthalenes; diphenyls and acenaphthenes; anthracenes, etc., in samples of thermally cracked, catalytically cracked, and straight run gas oils. D. H.

2424. Infra-red spectrometry for analysis of refinery gas. A. Cornu. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 105–15. (In French.)—The optical density of the gaseous olefins, ethylene to butenes, is ten times that of paraffins up to pentanes. A special method for continuous analysis of mixtures of these gases is described in detail. Special precautions have to be taken for the measurement of methane, which does not follow Beer's law.

The results show that each of the twelve constituents of a refinery gas may be determined with an average accuracy of the order of 0·7% absolute. D. H.

2425. Analytical hydrogenation of petroleum oils. M. R. Lipkin, C. C. Martin, and R. C. Worthing. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 68–80.—An investigation of variables resulted in an improved hydrogenation procedure, using solvent catalyst to oil ratios above 10, and delayed addition of the sample at the operating temp. The operating temp is 250° C, and the pressure of hydrogen charged is 2000 p.s.i.

Greater than 97% conversion can be obtained on most samples in one or two hydrogenations. Safety precautions are also described.

A criterion for judging completeness of hydrogenation was developed, using the ultra-violet absorption spectrum in the range 240 to 290 mμ. D. H.

2426. Catalytic removal of oxygen from sour cracked gases. C. G. B. Hammar. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 483–7.—In pilot scale desulphurization of a Swedish shale gas containing 20% H_2S and 1% O_2 by absorption in an alkaline amino acid solution it has been observed that the alkali consumption and the lifetime of the solution depend primarily on the oxygen content of the gas. An apparatus has been developed for continuous analysis and recording of oxygen content.

The accuracy of the method and its suitability for commercial process are discussed. D. H.

2427. Analysis purification, and properties of hydrocarbons. F. D. Rossini. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 1–10.—A survey is given of the investigation of the composition of petroleum as carried out by API Research Project 6.

Distillation, adsorption, extraction, etc., were used to separate components, and simple properties were measured accurately. Data on 118 hydrocarbons are listed. Procedures for purifying and testing are referred to. D. H.

2428. The constitution of heavy petroleum fractions. K. van Nes. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 21–39.—Investigation of structural groups in kerosine, gas oil, waxes, lub. oils, and bitumens has been by fractional distillation and crystallization, thermal diffusion, selective adsorption, and urea fractionation. The methods of calculation of the proportions of aromatic, naphthenic, and paraffinic groups are described with examples. The direct method is compared with the new *n-d-M* analysis based on simple physical properties. D. H.

2429. Method of determining the proportions of paraffins and naphthenes in petroleum fractions 175° to 300° C. R. Sigwalt and A. Chmelevsky. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 40–52. (In French.)—Fractional crystallization separates all N-paraffins and some *iso*paraffins in a practically pure state for analysis. The *iso*-paraffins which remain with the naphthenes are conveniently determined by refractive index. With supplementary aids, the precision of the determinations is $\pm 5\%$.

It is possible to subject the values of the various physical characteristics to a judicious examination, thus forming a basis for an identification analysis by calculation. (Authors' Abstract.) D. H.

2430. Contribution to the investigation of oils for carburation. P. Schläpfer and R. Köszegi. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 448–59.—Experiments were carried out which proved the necessity of laboratory research, under conditions similar to those prevailing in large-scale operation, to make classification of carburation oils possible.

Experimental conditions have to represent faithfully plant operation as regards temp, reaction time, and admixture of additional gas. Evaluation of carburating oils, based only on their chemical and physical properties, is inadequate.

Details of the experiments and conclusions are given. D. H.

2431. Some developments in the determination of small impurities and minor constituents in hydrocarbon gases. W. Roman. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 460–73.—The modern methods of determination of small amounts of one hydrocarbon gas in others are reviewed. It is shown that the measurement of thermal conductivity can be used, for example, to determine 0 to 1% methane in ethylene with an accuracy of $\pm 0{\cdot}3\%$. Approx values for the thermal conductivity of C_4 hydrocarbon gases have been determined.

A new method for water in hydrocarbon gases permits estimation of $5{\cdot}10^{-7}$ g. D. H.

2432. Sulphur compounds in propane: analysis and removal. Ch. Vernet. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 474–82. (In French.)—The sulphide and carbon oxysulphide produced in the thermal reforming process are the two compounds liable to be present as impurities in propane after rectification.

A rapid qualitative analysis sensitive to 1 mg of H_2S per kg of propane is proposed.

An electrometric titration of carbon has been used in the study of refinery products. Quantities comparable with those of the H_2S were found after reforming. The max was 200 mg/kg of propane.

Elimination of carbon oxysulphide by mono-ethanolamine is the best industrial method. D. H.

2433. Application of the Rosenmund–Kuhnhenn iodine value method. K. W. Rosenmund and H. H. Grandjean. *Erdöl u. Kohle*, 1952, **5**, 348–9.—Normal Rosenmund–Kuhnhenn I val procedure is designed for fatty oils and modifications are required for its application to low I val materials (*e.g.*, liquid paraffin). Main change suggested is use of N/100 pyridine bromide solution; excess Br should be determined iodometrically instead of by the arsenite procedure permitted by D.A.B.6. Three examples given in full experimental detail. V. B.

2434. Determination of oil content of soluble oil dispersions. IP Cutting Oils Panel of Standardization Sub-Committee No. 6—Lubricants. *J. Inst. Petrol.*, 1952, **38**, 58–68.—The method submitted by the Cutting Oils Panel consists of splitting a known vol of soluble oil dispersion with 20% hydrochloric acid in a graduated flask and measuring the vol of oil liberated. Several alternative splitting agents were investigated, and results on them are recorded. A. R. W. B.

2435. The identification of bitumens by colorimetric methods. D. C. Broome and R. M. Edwards. *J. Inst. Petrol.*, 1952, **38**, 88–97.—A method for the identification of the bitumen present in road and building asphalts was proposed by the authors in 1935, and a summary is given of the results over a number of years of the practical application of this method. The bitumen present in an asphalt is dissolved out with benzene, and the light absorption characteristics of the solution are measured photoelectrically over the range of the visible spectrum. The application of this method to various problems connected with the manufacture and use of asphalt is discussed. A. R. W. B.

2436. Classification of bitumens in asphalt technology by certain rheological properties. Pt I. Use of viscosity and consistency tests in the classification of asphaltic bitumens : a critical survey of existing knowledge. Pt II. Conception and derivation of viscosity number and other related new indices. S. L. Neppe. *J. Inst. Petrol.*, 1952, **38**, 109–51 ; 257–80.—Pt I. A survey of the literature, various aspects of the standard tests and their inter-relationships are discussed. Graphical methods used previously for relating visc and temp are examined and some improvements suggested, certain anomalies in the present system of standard penetration values are also pointed out. The present position regarding the classification of asphaltic bitumens is summarized, and the utility of various temperature-susceptibility factors and penetration indices is discussed.

Pt II. From experiments on a wide range of bitumens a graphical study has been made of the relationships between various rheological properties of asphaltic bitumens. Three new methods of classification have been developed in which identical index values have been assigned to each class of normal bitumens. These are :—

(*a*) Visc No.—relating visc at any one of three temps with bitumen penetration at 77° F ;
(*b*) Soft. pt. No.—relating soft. pt. and penetration.
(*c*) Soft. pt. Visc No.—relating visc with soft. pt.

Equations are presented for different classes of bitumen relating viscs with soft. pts. The general adoption in bitumen investigations of a modified form of trough viscometer is advocated. A. R. W. B.

2437. Methods for expressing the viscosity–temperature relationship of lubricating oils. J. F. T. Blott and C. G. Verver. *J. Inst. Petrol.*, 1952, **38**, 193–226.—Methods previously proposed for expressing the visc–temp susceptibility of lubricating oils are reviewed. A new relative index, called the Viscosity Modulus, is proposed which is a modification of the present V.I. in which the logarithms are substituted for the plain values of *V*100° F, viz. :

$$\text{Viscosity Modulus} = 100 \times (\log_{10}L - \log_{10}U)/(\log_{10}L - \log_{10}H)$$

U, *L*, and *H* being the kinematic viscs at 100° F of the oil under test and the two standard series respectively. For the *L* and *H* series the use of the values published by Hersh, Fisher, and Fenske is advocated. The advantages of this modulus are discussed, and a table is presented to facilitate its calculation. A. R. W. B.

2438. Electrical rotation viscometers for automatic measurement, recording and control of viscosities of fluid products. A. Wesp. *Erdöl u. Kohle*, 1952, **5**, 296–9.—Difficulties encountered in measurement of visc of complicated fluid systems using common types of viscometers are discussed. For non-Newtonian fluids the non-linear relationship between shear force and velocity gradient must be taken into account. Highly complex systems can be successfully investigated with two newly developed electrical rotation viscometers. One is a "compensation viscometer," in which thermostatically controlled conditions are maintained. Two coaxial hollow cyl are freely pivoted, the

outer being revolved at const speed, the inner being supported in frictionless bearings; the test fluid is placed in annulus. Drag on inner cyl is exactly compensated by an electrical device incorporating a photo-electric cell coupled to a direct reading indicator (1 to 100,000 cp). Second instrument consists of freely pivoted cylinder placed inside a thermostatically controlled cylindrical vessel. Known adjustable rotational moment is applied to inner cyl by a Ferrari induction system. Applied moment is opposed by that due to frictional forces of test fluid in annulus, and the resultant speed of rotation is a function of the fluid visc. Range of instrument is 100 to 50,000 cp. Advantages of new instruments: remote indication, recording, regulation, etc., can be easily incorporated; continuous visc control of liquid products; automatic recording of visc of thixotropic liquids; simultaneous automatic measurement of visc at two different temp by using two instruments; accurate temp control by Höppler thermostat; small vol of test liquid. P. V.

2439. Solvent refining control and assessment test. A. Giraud and M. Hellin. *Rev. Inst. franç. Pétrole*, 1952, **7**, 134–9.—Silica gel adsorption analysis method of Hibbard (*cf.* Abs. No. 1030—1949) has been employed for examination of efficacy of furfural extraction treatment. Refinery feed was medium Aramco dist which, with raffinate and extract, was de-waxed (M.E.K. at −15° C) prior to analysis; wax contents being 35·8, 51·1, 2·6% respectively. Fractions recovered from silica gel column were tested for n_D^{20}, an. pt. (or furfural pt.), V.I. (range 121 to −170), *d*. Properties are plotted against vol yield; curves indicate poor selectivity of solvent refining, considerable loss of paraffinic components in extract being necessary in order to reduce cyclic content of raffinate to a min. Method is suggested as applicable to refinery control. V. B.

2440. Examination of lubricating oil oxidation products. E. Matsas. *Rev. Inst. franç. Pétrole*, 1952, **7**, 83–95.—Tests were carried out on used oil from gas engine operating on natural gas. After dilution with C_6H_6, and centrifuging, deposit was freed from oil by washing with C_6H_6 and then treated with desorbing solvent (C_6H_6 61%, CH_3OH 39%); latter developed on basis of tests with various solvent mixtures (results tabulated) to determine best flocculating efficacy on used oils. Material thus obtained was separated into fractions by successive extractions with CH_3OH, $(CH_3)_2CO$, $CHCl_3$, C_6H_6; on each fraction elementary and infra-red analyses were done. Presence of N was detected, in form of amino acids and acid amides, presumably arising among oxidn products by action of atmospheric N. Application of an electrophoretic method is described whereby materials adsorbed by suspended matter in oil can be separated. Examination of effect of flocculating solvents indicates that these cause sign reversal of charge on suspended particles, the inversion point varying with flocculant concn. V. B.

2441. A study of decomposition products of used oil, and establishment of a test apparatus. E. Matsas. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 437–47. (In French.)—Used oil is stripped of solid and colloidal components before solvent extraction with acetone, *iso*propyl alcohol, methyl alcohol and methyl cyanide, and with three azeotropic mixtures. Unused oil was also treated in this manner in an attempt to find the least stable fractions. Full results are presented. D. H.

2442. Middle East type crude Aramco. G. Marot. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 353–71. (In French.)—Laboratory and industrial tests made on petrol, kerosine, and gas oil include for each cut: yield, density, copper number, Doctor, corrosion, sulphur and ASTM dist at B.P., 5%, 50%, 95%, F.B.P., clear and lead O.N., R.V.P., freezing points, cetane No., Engler visc.

Typical industrial cuts and their treatments and final specifications are included. D. H.

2443. Method for estimating cetane number. H. D. Young. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 420–36.—Comparison is made between diesel index, characterization factor, ignition quality No., modified ignition quality No., and calculated Cetane No. Calculated Cetane No. was found to give best correlation, accuracy, and convenience of use.

865 fuels were tested, and a nomograph is presented relating Cetane No. to API

gravity and mid boiling point for 50% recovered (ASTM dist). It is accurate to 2 Cetane Nos. over the range 30 to 60 for 75% of the fuels tested. Among the limitations of this correlation are cetane improvers, pure hydrocarbons, synthetic, alkylate, or coal tar fuels. D. H.

2444. Summary of NACA research on anti-knock characteristics of hydrocarbons and ethers. H. C. Barnett. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 397–419.—Results are summarized of a NACA investigation conducted over a period of several years to evaluate the anti-knock characteristics of organic compounds. Included are data for eighteen branched paraffins and olefins, twenty-seven aromatics, and twenty-two ethers.

The factors of performance investigated were blending characteristics, temp sensitivity, lead response, and relation between mol structure and anti-knock ratings. With consideration for all of these performance factors it is concluded that *tert*-butyl benzene, methyl and ethyl *tert*butyl ethers, and 2 : 2 : 3-trimethyl butane and several nonanes are among the best compounds in their respective classes. (Author's Abstract.) D. H.

2445. Significance of standard methods of test in engines and rigs. R. Stansfield. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 388–96.—Reference is made to twenty standard or widely used methods of test for fuel or lubricants under the headings Laboratory O.N.; Road O.N.; Cetane No.; Laboratory engine tests on lubes; Laboratory rig tests of transmission lubes; Tests of transmission lubes in vehicles.

The purpose of each test and relation between results obtained and service behaviour are outlined. References are given to the details of procedure in the literature. D. H.

2446. Laboratory pipe still. R. Dupas and B. de Saint-Leger. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 381–7. (In French.)—5 litres/hr of high visc oils can be distilled in this still without decomposition. A coil containing 20 ft of steel tubing ¼ inch dia is heated by a molten metal bath. Four perforated plate columns 4 inches dia, 8 inches high, separate the bitumen, cyl oil, heavy distillate, and light oil: gas oil is removed by refrigeration. Coil temp of 400° C and vacuum of 2 to 4 mm Hg was maintained, and the results of a typical run are given. D. H.

2447. Patents. Ger.P. 828,316, 13.12.51. W. Siebert, assr to Bad. Anilin- & Soda-Fabr. Procedure for the estimation of constituents in gas mixtures by means of radiation absorption.

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Crude Oil

2448. Mers-el-Kharez (Morocco) crude. Anon. *Rev. Inst. franç. Pétrole*, 1952, **7**, 123–33.—Evaluation carried out in similar manner to that for Sidi Fili crude (*cf.* Abs. No. 1128), which it closely resembles. Paraffinic crude had d_4^{15} 0·851, flash (closed) 36·5° C, wax 4·8%, S 0·12%, hexane-insol 3·9%, visc 30° C 1·9° E, pour 20° C. Pilot-plant atm/vac dist separated crude into 1% cuts (analyses given) and 12·1 vol-% residue. Characteristics of following products prepared from fractions are given: gasolines (O.N. (F2) 27 for 96° to 185° C cut), jet fuels, kerosines, diesel fuels (Cetane No. 66). Dewaxed lub cut (pour −18° C, visc 100° F 96·3 cs) had V.I. 63. Vac residue had d_4^{20} 1·03, hexane-insol 30·6%, m.p. (R. & B.) 84° C. V. B.

2449. Middle East type crude; lubricant fractions. R. Dupas. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 372–80. (In French.)—This study deals with yield and quality of lubricating oils from Iraq, Kuwait, and Aramco crudes. Each crude has been investigated as follows: separation of lub. fractions by dist and deasphalting of the residues; study of treatment with phenol, dewaxing, and clay treatment.

Although the crudes have analogous properties, the study justifies the following conclusions: Aramco is by far the most attractive. Iraq crude contains more bitumen and less oil. Kuwait crude makes high demands on the deasphalting installations. All the crudes may yield excellent motor oils of high V.I. (Author's Abstract.) D. H.

Gas

2450. Economics of natural gas and liquefied petroleum gases. B. R. Carney and B. J. Thompson. *Mech. Engng*, June 1952, **74** (6), 467.—Natural gas production in the U.S. has increased by 50% since 1945, and present-day known reserves of natural gas, including the liquid content, represent 60% of the total known petroleum reserves of the U.S. Comparative energy costs for various sources of power and uses are tabulated. In the authors' opinion natural gas will cease to compete for bulk fuel uses such as steam generation, owing to the growing demand for gas for applications where cleanliness and convenience outweigh costs. Storage reservoirs will be necessary to meet the fluctuating demands of non-bulk buyers. Exploration for natural gas will become extensive if the price increases by 50%. The annual recovery of liquefied petroleum gas from field plants is 86,000,000 brl, and it is estimated that an increase in price of L.P.G. from 4·0 to 5·6 c/gal would result in a 50% increase in production. Factors affecting continued growth of the industry are discussed. Nine references.

T. T.

2451. Gas supply and requirements in California. S. A. Bradfield. *J. Petrol. Tech.*, Jan. 1952, **4** (1), 15–17.—California's population has trebled since 1920. In 1935 1,486,640 general service customers used 71,638,340 M.c.f. of gas; in 1950 2,880,180 customers used 249,315,565 M.c.f.

California's major industrial expansion began in the first world war, and with the main oil development. Much of the gas output is linked with oil production. Twenty-five years ago California's gas supply was more than ample for all needs. Since then there has been increased gas consumption in field and refining operations. Repressuring removes 500 M.M.c.f/day from the markets. Gas is now imported from West Texas and the San Juan basin. Deliveries of 405 M.M.c.f/day began in 1950.

Much of the industrial gas usage is on an interruptible basis, the supply being curtailed when gas is needed for firm use. This permits the use of a high load factor on long transmission lines. However, winter demand exceeds the normal supply, and in summer there is excess gas, and in some areas there is gas storage as at La Goleta and Playa del Rey.

A commission has recently studied the present and potential demands for an availability of gas in California. It is considered that to meet the estimated peak day firm demand by the winter of 1952–53 additional reserves may be needed.

G. D. H.

2452. Western Canada's natural gas. F. K. Beach. *World Petrol.*, 1952, **23** (5), 78–81.—Exclusive of development wells and mountain and pre-Cambrian outcrop areas, well density in Alberta is only 1 : 130 sq. miles. In 1951, 1197 wells were drilled, 405 being exploratory and 305 rank wildcats, forty-six of latter were gas discoveries. Two and three discoveries were made in Saskatchewan and British Columbia respectively. History of gas production is traced from Canadian Pacific find in 1883 water well to present day. Recent Leduc and Redwater oil discoveries end synthetic oil plans. Alberta legislation makes exploitation dependent on there being adequate reserves for future provincial need. Estimates have therefore been made of reserves. At end of 1951 104 fields contained 11,700 billion cu. ft. proved and probable, five fields having 1000 billion cu. ft. each. Various projects for export are discussed, and a map of Alberta shows oil and gas fields and pipelines.

E. B.

2453. Petroleum refinery gas as a public utility. A. R. Myhill. *Mech. World*, June 1952, **131** (3395), 274.—It is estimated that by 1954 there will be available in the U.K., 450,000 tons per annum of liquefied petroleum gas surplus to the needs of the petroleum industry. The propane fraction has a cal. val. of 2500 B.Th.U/cu. ft. and the butane 3400 B.Th.U/cu. ft. Normal town gas appliances cannot be used with neat petroleum gas. When the gas is used for peak load additions by gas-works, the cal. val. of the town gas is lowered by recognized methods, and then raised to its normal value by the addition of petroleum gas, thus enabling customers' existing appliances to be used with no adjustment. For some time the Manchester gas undertaking has been supplied with tail gases, consisting mainly of methane and hydrogen, from a nearby refinery,

and in Abergavenny 300,000 to 400,000 cu. ft/day of butane gas have been used as an emergency addition to the normal gas-works supply. In Wales, two schemes have been installed to make a butane–air mixture with a cal. val. of 750 B.Th.U/cu. ft. One scheme incorporates two blowers, one for butane and one for air, controlled to give a constant butane–air proportion. In the other installation butane vapour passing through a venturi aspirates the correct amount of air. T. T.

2454. Patents. Ger.P. 832,144, 24.1.52. E. V. Harlow, assr to Koppers Co. Device for separation and concentration of gases by diffusion.

Ger.P. 832,036, 17.1.52. H. Brownley, assr to Allied Chem. & Dye Corpn. Procedure and installation for production of combustible gas from hydrocarbon oil. (Prior Amer. 2.9.49.)

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Engine Fuels

2455. Draft [German] specifications for liquefied automotive fuel gas. T. Hammerich. *Erdöl u. Kohle*, 1952, **5**, 361–6.—Comments on delivery requirements, covered by DIN 51620. Max v.p. (40° C) is 16·7 kg/cm², lower cal. val. (calcd) 10,600 k.cal/kg min, inert and high b.p. components 3% and 1% max respectively. Winter and summer grades are specified, varying in C_4 content. Elementary S < 1·5 mg/kg, H_2S < 0·1 mg/kg. Text of following standards given: sampling, DIN 51610 (description of pressure bombs); analysis, DIN 51611 (Hammerich gas dist apparatus, or low temp atm pressure method, analysing for $C_1 + C_2$ and inerts, C_3, C_4, higher b.p. components; both apparatuses and procedures described in detail); cal. val. DIN 51612 (by calc from composition and tabulated values for cal. val. of individual hydrocarbons). V. B.

2456. Pilot-plant scale production of aviation gasolines. A. Guillemin. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 231–43. (In French.)—A naphtha of a high aromatic content, obtained by catalytic conversion of a straight-run naphtha, topped from a Middle East crude, could be utilized for the production of two types of aviation gasoline. One was a 91/96 type gasoline using, in addition to the aromatic fraction, a light gasoline obtained by super-fractionation of the straight-run gasoline from a Middle East crude. The other was a 100/130 type gasoline made by mixing the same aromatic fraction with a Houdry catalytically cracked gasoline and technical grade *iso*pentane and *iso*-octane. This latter answers the specifications of corresponding aviation standards, and its rich mixture knock rating is 139 by ASTM D.909.

Tests on a stationary 12-cyl aviation engine show it is in all respects comparable to Military Air Services gasolines. D. H.

2457. Patents. U.S.P. 2,584,803 (7.8.46; 5.2.52). J. A. Hannum, assr to Borg-Warner Corpn. A self-sufficient fuel comprises nitromethane, nitroethane, 1-or-2-nitropropane, 1 : 1-, 2 : 2-, 1 : 2-, or 1 : 3-dinitropropane, 1 : 1-dinitroethane or 1 : 1 : 1- or 1 : 2 : 3-trinitropropane, an oxidant, and a polychlorofluoromethane as a flash-back suppressor.

U.S.P. 2,585,843 (8.1.49; 12.2.52). D. T. Rogers, assr to Standard Oil Development Co. Rusting in I.C. engines operating on leaded fuels is prevented by burning in the engine, prior to a period of idleness, a fuel containing 0·01 to 1·0 wt-% of a partial ester of a polyhydric alcohol and a fatty acid.

U.S.P. 2,586,660 (1.3.50; 19.2.52). W. C. Howell, assr to Standard Oil Development Co. Leaded gasoline containing 0·5 to 1 theories of halogenated hydrocarbon scavenger and a volatile alkyl tin compound. 0·5 to 1·5 atoms of tin are present per atom of lead. J. M. S.

Gas Oil and Fuel Oil

2458. Commercial burner oil specifications. J. V. Resek. *Mech. Engng*, June 1952, **74** (6), 475.—A revision of the standard specification for domestic and industrial fuel oils, CS 12–48, is proposed. The oil-burner industry is trying to establish a new unit

of comparison of the burning qualities of fuel oils, but no conclusive proof that any of the proposed tests provide a reliable index has been submitted. Such characteristics as fl. pt., pour point, visc, gravity, free carbon, and end point must be relied on. The significance of these characteristics is discussed, and recommendations for suitable fuels for use with various types of oil burners are given. Former, present, and proposed specifications are tabulated, and the differences between them are commented on. Six references. T. T.

2459. Patents. U.S.P. 2,584,281 (20.12.48; 5.2.52). H. E. Morlock. A pot type oil burner has a bowl-shaped metal body with a bottom cavity extending below its lower surface, a rigid porous wick lying in the cavity and extending above the said lower surface, a flexible porous wick in the form of a disk surrounding the rigid wick, means for supplying air, to support combustion at both wicks, downwardly and inwardly within the body and means for supplying fuel to the cavity for absorption by both wicks.

U.S.P. 2,584,805 (18.7.45; 5.2.52). R. F. Leftwich. A method of burning an emulsion of water, fuel oil, and finely divided solids is described.

U.S.P. 2,585,088 (5.8.49; 12.2.52). S. W. Burch. A vaporizing fuel oil burner having a vaporizing chamber in heat exchange relationship with the combustion chamber.

U.S.P. 2,585,431 (5.10.46; 12.2.52). J. L. Breese, assr to Breese Burners Inc. Metering valve for liquid fuel burners.

U.S.P. 2,587,078 (22.1.49; 26.2.52). P. Wollner. Vaporizing type oil burner.

U.S.P. 2,587,140 (28.8.48; 26.2.52). A. S. Gorshkoff, assr to Steel Products, Inc. Diffuser head for liquid fuel burners.

U.S.P. 2,587,361 (15.8.47; 26.2.52). C. A. Miller, assr to Kresky Mfg. Co. Inc. Horizontal tray-type oil burner. J. M. S.

2460. Patent. Ger.P. 831,546, 17.1.52. G. Free, assr to Bad. Anilin- & Soda-Fabr. Process for the manufacture of anti-knock motor fuel from crude oil containing petrol.

Brennstoff-Chem., 1952, **33** (3–4). R. T.

Lubricants

2461. Progress in the science and art of lubrication. E. V. Paterson. *Petrol. Times*, 27.6.52, **56**, 527.—Specification DEF/2101 for three grades of heavy duty crankcase lubricating oil and the new draft BSI specification for heavy duty oils in the range SAE 10W to SAE 50 are discussed.

Chromium plating, aluminium cyls and plated piston rings, coolant claims, and a new method for determination of oil content of soluble oils are among other subjects dealt with in this quarterly review. G. A. C.

2462. Some views on the SAE viscosity classification. J. G. Withers. *J. Inst. Petrol.*, 1952, **38**, 250–6.—It is suggested that the working visc of all grades of engine and transmission oils should be specified in cs at 210° F, and a rationalization of the limits for different grades is put forward based on a logarithmic relationship.

Recommendations are made for suitable grades of engine and transmission oils for use in Europe. A. R. W. B.

2463. Simple procedure for testing lubricants at limiting friction. M. Pfender. *Erdöl u. Kohle*, 1952, **5**, 342–8.—Testing of lubricants at high pressures and low slip rates is accomplished by compression (load = 2000 kg) between flat surfaces, of soft Pb cyls (6 mm dia, 5 mm ht), distortion of which (widening, shortening) is influenced by lubrication at point of contact with pressure surface. Tests were made with various soaps (analyses given) and lub oils. Lubricity (expressed as recip of coeff of friction) for soap solutions (in H_2O) increases rapidly with concn up to 0·1%, with further slight rise to about 10%, and then falls sharply, so that lubricating action of 100% solution

is approx that of a 0·002% solution, this is probably due to non-dissociation of conc soap solution, yielding merely effect of alkali solution; tests with latter indicated only slightly more lubricating effect than for pure water, which itself gave result close to that for the dry material. Pet lub oil, rape oil, and tallow gave good lubricity, approaching that of soap; synthetic oils (with one exception) gave low values. Photographs are given showing spreading of Pb cyls under test conditions. V. B.

2464. Is 1000-mile oil change a must? Anon. *Petrol. Process.*, Apr. 1952, **7** (4), 486–8. (*See also* Abs. 1486.)—Further data are reported by W. F. Weiland in support of his theses regarding the relation between acid vapour temp (A.V.T.) of the lube oil and bearing corrosion in car and lorry engines. Letters are published which, in the main, agree that a 1000-mile oil change is desirable, but disagree that any correlation of A.V.T. and lube oil breakdown is established. Replies by Weiland are included. D. W. F.

2465. Blend motor oils the modern way. R. G. Atkinson. *Petrol. Process.*, Apr. 1952, **7** (4), 470–4.—A continuous automatic oil-blending plant, as in use at a Standard Oil Co. (Ohio) refinery, is compared with the older type of batch blending equipment. The main objections to the batch process are eliminated in the continuous one, as the components are automatically metered and controlled to a blending manifold, from where the blended oil gas goes to a rotating-disk type flash evaporator for moisture removal. The required percentages of each component is set on the control panel, blending ceasing when the predetermined volume of blended oil has passed from the unit. D. W. F.

2466. Organizing the lubrication of machine tools. E. Van Emden. *Ingenieur* 20.6.52, **64** (25), W39–41.—The possibilities of centralizing the task of lubricating the machine tools in metalworking factories are discussed. Emphasis is laid on a systematical choice of the right lubricant, applied at the right time, and on a drastic limitation of the number of lubricants. (Author's Abstract.) G. F. T. C.

2467. Preservation and lubrication of machine tools. R. Snel. *Ingenieur*, 20.6.52, **64** (25), W41–4.—Corrosion phenomenon and the inadequacy of undoped lube oils in preventing it are described. Some properties of water-displacing agents are given.

The special lubricating requirements for modern machine tools in order to avoid overheating, stick-slip, etc., are dealt with. Defective technical hygiene may result in contaminated cutting-oils causing dermatitis. Finally, the special properties of heat- and water-resisting lubricating greases are discussed. G. F. T. C.

2468. The lubrication of electric motors. A. F. Brewer. *Petrol. Process.*, May 1952, **7** (5), 632–7.—Different types of motor-shaft bearings, such as sleeve, ball, and roller bearings, are described with the aid of drawings and cut-away photographs. The lubricant required is dependent upon the type of bearing and the service to which the motor is applied. The sleeve bearings may be lubricated by ring, wick, or wool yarn packing around the shaft. The function and location of the oil groove on the shaft are considered. The limited quantity and rapid rate of circulation of the oil in sleeve bearings demands careful selection of oil quality and visc. Ball and roller bearings in general have no circulating lubricant, but are packed with special greases and must be serviced as units. The oil seal is of greater importance with ball and roller bearings. Procedures to be followed are given for cleaning and flushing bearings. D. W. F.

2469. Patents. U.S.P. 2,583,603 (18.12.48; 29.1.52). A. F. Sirianni and I. E. Puddington, assrs to The Honorary Advisory Council for Scientific and Industrial Research (Canada). Grease comprising a mineral lub oil thickened by 1 to 20% of an inorganic oxygen-containing gel voluminous precipitate having its normal liquid content replaced by said oil and ½ to 20% of a polystyrene waterproofing agent covering said precipitate to inhibit moisture absorption thereby.

U.S.P. 2,584,085 (20.7.48; 29.1.52). F. H. Stross, assr to Shell Development Co. Lubricant comprising 5 to 20 parts of an oleaginous substance, 1 part of an inorganic grease-forming gel, and ½ to 5 parts of a polymerization product of an organosilicon halide adsorbed on said gel, which latter is dispersed in the oleaginous substance.

U.S.P. 2,583,604 (18.12.48; 29.1.52). A. F. Sirianni and I. E. Puddington, assrs to The Honorary Advisory Council for Scientific and Industrial Research (Canada). Lub grease comprising an oily synthetic ester of a dibasic acid thickened with 1 to 20% (of the total weight) of silica gel, whose normal water content is replaced by said ester, and 10 to 100% (by weight of the gel) of an organosilicon polymer waterproofing agent.

U.S.P. 2,583,605 (18.12.48; 29.1.52). A. F. Sirianni and I. E. Puddington, assrs to The Honorary Advisory Council for Scientific and Industrial Research (Canada). Lub grease consisting of mineral lub oil thickened with 1 to 20% of silica gel and 10 to 100% (by wt of the gel) of a linseed oil modified alkyd resin as a gel-waterproofing agent.

U.S.P. 2,583,606 (18.12.48; 29.1.52). A. F. Sirianni and I. E. Puddington, assrs to The Honorary Advisory Council for Scientific and Industrial Research (Canada). Lub grease consisting of a mineral lub oil thickened with silica gel which has its normal water content replaced by said oil and 10 to 100% (by weight of the gel) of an organosilicon polymer $\left[\frac{R}{R}\!>\!Si—O\right]$, where R is alkyl or alkoxy.

U.S.P. 2,583,607 (18.12.48; 29.1.52). A. F. Sirianni and I. E. Puddington, assrs to The Honorary Advisory Council for Scientific and Industrial Research (Canada). Lub grease consisting of a mineral lub oil thickened with 5 to 20% of a complex polyvalent metal salt of one molar part of C_{12} to C_{24} fatty acid to 3 to 15 molar parts of C_2 to C_6 dibasic carboxylic acid, the salt having its normal water content replaced by said oil. R. C. R.

2470. Patents. U.S.P. 2,584,977 (9.7.46; 12.2.52). J. D. Bartleson, assr to The Standard Oil Co. Mineral oils, particularly lubricating oils, are stabilized against oxidation by addition of a cation radical derivative of a reaction product made by heating at 400° F one mole of an aliphatic nitrile having 12 to 18 carbon atoms with 0·1 to 1·0 moles of a phosphorus sulphide, from 0·25 to 6·0 equivalents of alkali metal cation being present in the additive per mole of sulphide in the reaction product.

U.S.P. 2,585,182 (18.3.47; 12.2.52). S. Sterman, assr to Union Carbide and Carbon Corp. Lubricating grease comprises a di-2-ethylhexoate ester of tri- or tetra-ethylene glycol and 5 to 25% by wt lithium hydroxystearate.

U.S.P. 2,585,321 (13.6.50; 12.2.52). R. A. Butcosk, assr to Socony-Vacuum Oil Co. Inc. High temp grease consists of mineral oil, 5 to 25 wt-% lithium soap, and 10 to 50 wt-% ester of an oxyacid of phosphorus.

U.S.P. 2,585,520 (3.12.48; 12.2.52). P. R. Van Ess and H. E. Sipple, assrs to Shell Development Co. Oil-soluble highly basic petroleum sulphonates, suitable as additives for mineral lubricating oils, are made by treating an oil-soluble petroleum sulphonate of a strongly basic Group II metal dissolved in a water-immiscible solvent with an alcoholate of a similar metal and subsequently hydrolysing the alcoholate.

U.S.P. 2,585,813 (23.4.49; 12.2.52). J. P. McDermott, assr to Standard Oil Development Co. Hydrocarbon oils containing a mixed acid anhydride of the formula $(RO)_2PSSSO_2R'$, wherein R and R′ are hydrocarbon radicals. The additive is an antioxidant.

U.S.P. 2,585,820 (2.7.34; 12.2.52). Le G. Morell and A. T. Knutson, assrs to The Dow Chemical Co. Mineral lubricating oil containing a non-volatile chlorinated paraffin hydrocarbon.

U.S.P. 2,585,862 (1.11.49; 12.2.52). P. V. Smith and A. H. Popkin, assrs to Standard Oil Development Co. Synthetic lubricants comprising a compound of the formula RCOOR″SR″OOCR, wherein R represents an alkyl radical of 8 to 20 carbon atoms and R″ represents an alkylene radical of 2 to 5 carbon atoms. One of the radicals R is an Oxo radical of 8 to 11 carbon atoms.

U.S.P. 2,585,877 (21.4.49; 12.2.52). H. S. Trigg, H. D. Norris, and R. V. White, assrs to Socony-Vacuum Oil Co. Inc. Mineral lubricating oils contain an ester of a trialkylammonium acid salt of a hydroxy aliphatic dicarboxylic acid and a primary aliphatic monohydric alcohol. The additive improves anti-wear properties and cutting efficiencies.

M M

U.S.P. 2,586,191 (21.8.48; 19.2.52). D. Wasserman, assr to The Harvel Corpn. Corrosion and oxidation characteristics of lubricating, aviation, diesel, and turbine oils are improved by addition of a metal salt of a sulphonic acid of an ether of hydrogenated cardanol.

U.S.P. 2,586,690 (29.5.48; 19.2.52). L. A. Mikeska, assr to Standard Oil Development Co. Pour depressants are made by modifying a Friedel–Crafts condensation product of a chlorinated wax and phenol by reaction with a 2-chloroethyl thioether containing an alkyl group of 8 to 18 carbon atoms in the presence of aluminium chloride.

U.S.P. 2,586,693 (1.11.49; 19.2.52). A. J Morway and L. A. Mikeska, assrs to Standard Oil Development Co. A lubricating grease comprising a lubricating oil and alkali metal soaps of a mixture of high mol wt saturated fatty acids, fatty acids having 1 to 4 carbon atoms, and an aryl-aliphatic acid having 8 to 20 carbon atoms in the aliphatic group.

U.S.P. 2,587,017 (5.11.47; 26.2.52). W. F. Weber, assr to Armour and Co. Lubrication of conveyer apparatus for meat is effected by means of a mixture of 65% paraffin wax, 25% oil, and 10% microcrystalline petrolatum wax.

U.S.P. 2,587,545 (14.4.49; 26.2.52). L. W. Sproule and L. F. King, assrs to Standard Oil Development Co. Mineral lubricating oil containing 0·2 to 3·0% of a sorbitan monoester of a fatty acid having 16 to 18 carbon atoms and 0·2 to 3·0% of a glycol half-ester of a fatty acid having 10 to 16 carbon atoms.

U.S.P. 2,587,546 (30.10.48; 26.2.52). A. H. Matuszak, assr to Standard Oil Development Co. Mineral lubricating oil containing 0.5 to 1% of an oleic acid salt of mono-, di-, or tri-methylol amino methane. J. M. S.

2471. Patent. Ger.P. 829,163, 20.12.51. N. Geiser, assr to Ruhrchemie A.-G. Method for production of high-grade lubricating oils.
Brennstoff-Chem., 1952, **33** (3–4). R. T.

Bitumen, Asphalt, and Tar

2472. Asphalt in Argentina. Anon. *Bol. comision permanente del asfalto* (*Buenos Aires*), 1952 (6), 9–12.—Production of asphalt in Argentine, approx 12,000 tons p.a. in 1950, derived 64% from indigenous crude, 36% from imported (Venezuelan) crude. Indigenous asphalt made by vac reduction from two crudes, Comodoro Rivadavia and Challaco, 80 to 100 pen grade from former having softening point of 51° C, from latter 45° C. Blown asphalts also produced; for certain grades, Edeleanu extracts from heavy Comodoro Rivadavia lubs added before blowing. Tables showing properties of various asphalts given. A. C.

2473. Estimation of adhesive power and progress of hardening of bituminous road building binders. A. Scheurer. *Bitumen, Teere, Asphalte, Peche*, 1952, **2** (3), 29–35.—The apparatus consists essentially of the test unit operated by a crank and rack and pinion connected to a calibrated wheel balance. The machine is described in detail together with test procedure. The films obtained in the adhesion test are transferred to white paper, copied with printer's ink, or photographed for visual observation. Details are given of comparative tests on a series of binders which determine the magnitude of adhesiveness down to zero. The apparatus is applied as described to determination of the firmness of unctuous materials, fluid and dry friction in lubrication, coeff of friction, tendency to setting, inwardly progressing resinification, embrittlement of types of binders, and quant estimation of scratch resistance of binder films as affected by light, air, heat, water, and chemicals. Whereas conventional viscometers operate with three outflow nozzles and at four temp, visc curves are obtained with progressive temp rise or fall. Photographs, charts, and tabulations of results are presented. R. T.

2474. Oil from Alberta bitumen. G. W. Hodgson, B. Matchen, W. S. Peterson, and P. E. Gishler. *Industr. Engng Chem.*, 1952, **44**, 1492–6 (*cf.* Abs. 2668—1951).—Describes a pilot plant for simultaneously dehydrating and coking wet crude from

Alberta bituminous sand. The process is a continuous one using a fluidized bed, and is described as a possible alternative to the direct distillation of oil from the sand.

E. J. C.

2475. The design of flexible pavements. R. E. Kerkhoven. *Ingenieur*, 27.6.52, **64** (26), B89–95.—It is demonstrated that the application of the empirical CBR-method is also acceptable from a theoretical point of view. It is pointed out that there is a correlation between the vertical stress distribution and the trend of the CBR curves and that the CBR value may be considered as a deformation modulus. A general formula is developed, giving the total thickness of the road-carpet on a layer of a given CBR value in function of the radius of contact area, the tyre-pressure, and the number of load repetitions. Explanatory graphs and examples are included.

G. F. T. C.

2476. Patents. U.S.P. 2,584,300 (9.12.48; 5.2.52). C. D. Simmers, assr to Johns-Manville Corpn. A liquid binder which is curable by heat and oxidation consists of alkane polyol esters of tall oil carboxylic acids modified by a drying oil and a higher m.p. bitumen, and 0·5 to 1% of a drier.

U.S.P. 2,584,919 (28.6.49; 5.2.52). H. B. Pullar, assr to Berry Asphalt Co. A pulverulent, storage-stable bituminous composition consists of 25 to 75% by wt of powdered bitumen having a penetration of <5 at 77° F, substantially all of which will pass a forty-mesh sieve, and 25 to 75% by wt of finely divided barium sulphate, all of which passes a 325-mesh sieve.

U.S.P. 2,585,336 (14.6.48; 12.2.52). P. E. McCoy, assr to American Bitumels & Asphalt Co. A quick-breaking bituminous emulsion having improved adhesion for hydrophilic aggregate consists of water, bitumen, a water-soluble chromium salt of an oxyacid, and sulphonated tall oil.

U.S.P. 2,586,585 (14.9.49; 19.2.52). B. P. Wallace, assr to Whitehead Brothers Co. A moulding composition for metal-casting moulds consists of sand grains coated with bitumen or a petroleum still-bottom residue, bentonite, and an air-drying poylmer derived from petroleum distillates.

J. M. S.

2477. Patents. Ger.P. 832,154, 24.1.52. J. Geller and H. Ratte, assrs to Rütgerswerke A.-G. Process and installation for recovery of pure or technically pure constituents of coal tar.

Ger.P. 831,552, 17.1.52. E. Asser and H.-U. Schultze, assrs to Michael Barthel & Co., Regensburg. Process for separation of the constituents from bitumen pitches.

Ger.P. 832,155, 24.1.52. E. Moehrle, H. Franck, and A. Marx, assrs to Ges. f. Teerverwertung. Procedure for obtaining diphenyl and for indol from coal tar oil fractions.

Ger.P. 831,397, 10.1.52. K. Daimler, assr to Farbwerke Höchst. Method for production of bituminous dispersions.

Brennstoff-Chem., 1952, **33** (3–4).

R. T.

Special Hydrocarbon Products

2478. Patent. U.S.P. 2,583,938 (30.11.48; 29.1.52). A. French, assr to Standard Oil Co. Opaque wax articles are produced by melting together paraffin wax of m.p. between 120° and 140° F and up to 25% of microcrystalline wax melting above 145° F, aerating the melt to form a stable, opaque, free-flowing emulsion-like composition and solidifying the composition in a mould.

R. C. R.

2479. Patents. U.S.P. 2,584,139 (27.12.47; 5.2.52). R. E. Lidov and E. Segel, assrs to Velsicol Corpn, and J. Hyman. Diels–Alder adduct of a hexahalocyclopentadiene and benzoquinone or naphthoquinone.

U.S.P. 2,585,026 (4.10.48; 12.2.52). R. Moen and M. S. Dalquist, assrs to General Mills Inc. An aqueous emulsion of mineral oil is applied to grain to the extent of 0·02 to 0·08% of mineral oil based on the grain. Grain dust is reduced.

U.S.P. 2,585,755 (U.K. 18.12.50; 12.2.52). F. Duspira, assr to Pest Control Ltd. Insecticides consist of particles of highly chlorinated hydrocarbons coated with alkali-soluble coatings, such as alginic acid and cellulose acetate hydrogen phthalate.

U.S.P. 2,585,875 (11.9.47; 12.2.52). M. W. Swaney and L. Z. Jasion, assrs to Standard Oil Development Co. *p-tert*-alkyl chlorophenoxy acetic acids are plant hormone synergists, *e.g.*, for 2 : 4-dichlorophenoxyacetic acid.

U.S.P. 2,586,680 (28.12.46; 19.2.52). G. L. Matheson and L. A. Mikeska, assrs to Standard Oil Development Co. Zinc, copper, and iron salts of tetra*iso*butyl phenol sulphonic acid are parasiticides.

U.S.P. 2,586,681 (29.3.50; 26.2.52). J. F. McKay, H. L. Yowell, and L. Z. Jasion, assrs to Standard Oil Development Co. Herbicidal compositions consist of an aromatic petroleum oil and a mixture of oxygenated organic compounds obtained as still bottoms from alcohol synthesis by the Oxo process.

U.S.P. 2,586,793 (14.3.47; 26.2.52). A. E. Doty, J. E. Johnson, D. R. Mussell, and M. A. Wolf, assrs to The Dow Chemical Co. Bromoalkenes are used to prevent infection of domestic animals by coccidia. J. M. S.

Derived Chemical Products

2480. Acid sludge—its utilization and disposal. A. Cluer. *J. Inst. Petrol.*, 1952, **38**, 1–8.—A consideration of the acid sludge problem faced by one of the smaller British refineries. Acid sludge results only from a proportion of the lube oil output and from the preparation of industrial oils, technical white oils, and medicinal oils. Sludge from the industrial oil plant is dumped, but two systems of burning mobile sludges have been installed. A simple burner using air atomization with a $\frac{3}{8}$-inch tip of stainless steel has been found satisfactory. Recovery of sulphur dioxide is effected by flashing sludges obtained from the white oil plant in a flash evaporator—the sulphur dioxide released being sufficiently pure to be drawn directly to the Edeleanu plant recovery system. A. R. W. B.

2481. Acid sludge—its utilization and disposal. E. S. Squire, D. G. Pidgeon, and P. C. Jones. *J. Inst. Petrol.*, 1952, **38**, 8–20.—Liquid tars are destroyed by burning in an air-operated burner having a cast-iron nozzle which has a life of two to three weeks. In the case of more viscous, but still liquid tars, atomization is not attempted; the tar is broken up by high pressure steam over the incandescent bed of a chain grate stoker. Tars from the treatment of heavy lube oils can be allowed to harden and then hand stoked. Hydrolysis methods of recovering useful products are discussed—a plant was available at Abadan for diluting sludges and then reconcentrating the acid to recover 135 tons/day. An acid tar decomposition plant at Abadan is described in which tar is injected into a rotary kiln on to coke at 1000° F. The decomposition gases are passed to the SO_2 furnace of a contact acid plant. A. R. W. B.

2482. Acid sludge—its utilization and disposal. W. E. Nieuwenhuis. *J. Inst. Petrol.*, 1952, **38**, 21–33.—The handling of acid sludges rich in organic matter prior to burning is discussed.

Sulphuric acid may be recovered by dilution and reconcentration methods from light acid sludges. Two of the available types of concentrators, the Mantius and the Chemico, are described briefly. Alternatively, acid sludge may be decomposed to SO_2 by either high or low temp reduction and the SO_2 fed to a contact plant or used as such. The low temp Chemico and Monsanto–Ross methods are outlined, and a high temp process developed by Chemico is also described briefly. A. R. W. B.

2483. Acid sludge—its utilization and disposal at Manchester Oil Refinery. R. C. Cobley, H. Kaye, and R. K. Spencer. *J. Inst. Petrol.*, 1952, **38**, 33–41.—Details are given of a method employed by this refinery to burn its acid sludges for steam generation. Recovery of petroleum sulphonates and the extraction of weak acid from these sludges are mentioned as possible by-products which can be obtained. A. R. W. B.

2484. The industrial production of ethylene oxide. J. Plant. *Industr. Chem.*, 1952, **28**, 259–64.—Ethylene oxide is manufactured at Urmston, Manchester, plant of Petrochemicals Ltd from ethylene produced by cracking of light pet dist. Ethylene

is fed to stoneware-lined towers with water and chlorine, and reacts to form ethylene chlorhydrin. This is then "saponified" with milk of lime, and ethylene oxide dist from by-product ethylene dichloride and acetaldehyde. Ethylene oxide is used for production of ethylene glycols (anti-freeze, explosives, plasticizers), ethylene glycol ethers (solvents, brake fluid), and ethanolamines (detergents, cosmetics, dyestuffs).

A. C.

2485. Detergents from petroleum. S. F. Birch. *J. Inst. Petrol.*, 1952, **38**, 69–82.—A brief description of the physical behaviour of aqueous detergents is given.

The bulk of the anionic detergents currently produced from petroleum fall into the following main chemical types: secondary alkyl sulphates, alkanesulphonates, alkylarylsulphonates and alkanecarboxylates. The methods by which these products are obtained from the petroleum feedstocks available are described. The commercially available non-ionic detergents are all derivatives of ethylene oxide, much of which is produced from petroleum sources, and the preparation of such detergents is discussed.

A. R. W. B.

2486. Patents. U.S.P. 2,584,112 (30.8.50; 5.2.52). H. C. Brown assr to Standard Oil Co. Organic phosphines are made by contacting an olefin with phosphine and a strong non-oxidizing acid catalyst.

U.S.P. 2,584,325 (U.K. 25.8.47; 5.2.52). B. E. V. Bowen and J. Howlett, assrs to The Distillers Co. Ltd. Lower aliphatic alcohols prepared by treatment of olefins with sulphuric acid are deodorized by treatment with solid cuprous oxide.

U.S.P. 2,584,496 (25.10.45; 5.2.52). E. Pierson and M. Tishler, assrs to Merck & Co. Inc. 2-methyl mercapto-propionaldehyde is made by reacting methyl mercaptan and acrolein in presence of mercuric methyl mercaptide.

U.S.P. 2,584,589 (27.9.48; 5.2.52). E. L. Jenner, assr to E.I. du Pont de Nemours & Co. An olefin having from 3 to 8 carbon atoms is reacted with formaldehyde and an alkyl nitrile in presence of a strong acid and an alkyl monocarboxylic acid. The products are diacyl 1 : 3-amino alcohols.

U.S.P. 2,585,091 (14.11.47; 12.2.52). J. T. Clarke, assr to The Texas Co. Alkyl thiophenes are preferentially halogenated in the side chain by reaction with halogen at 450° to 750° F at a space velocity of at least 50 vols alkyl thiophene per hr per vol of reactor space.

U.S.P. 2,585,129 (3.3.48; 12.2.52). A. I. Gebhart and J. Ross, assrs to Colgate–Palmolive–Peet Co. Fatty acids are prepared by reacting a mono-olefin of at least 8 carbon atoms with peracetic acid dissolved in acetic acid, saponifying and acidifying the product to form a dihydroxy alkane, which is then treated with periodic acid to form a fatty aldehyde which is oxidized to the fatty acid with peracetic acid dissolved in acetic acid.

U.S.P. 2,584,861 (U.K. 21.1.49; 5.2.52). P. J. Garner and B. J. Donovan, assrs to Shell Development Co. Naphthenic acids are recovered from refinery residues containing naphthenates, by acidifying the residues to convert the naphthenates to naphthenic acids, dissolving the acidified residue in a light petroleum fraction, contacting the solution with an aqueous alcoholic solution of complex cupric ethanolamine sulphate to produce an aqueous alcoholic solution of complex cupric ethanolamine naphthenates, separating the aqueous and mineral oil phases, acidifying the separated aqueous phase, and separating the naphthenic acids from the aqueous phase.

U.S.P. 2,585,292 (17.8.50; 12.2.52). W. J. Zimmerschied and R. C. Arnold, assrs to Standard Oil Co. Alkyl thiophenes are made by reaction between thiophene or an alkyl thiophene and an alkyl iodide, bromide, chloride, or sulphate in liquid ammonia containing an alkali metal amide at a temp between $-50°$ and $+50°$ C.

U.S.P. 2,585,469 (20.5.48; 12.2.52). P. R. Johnson, assr to E.I. du Pont de Nemours & Co. Chloroform, carbon tetrachloride, and hydrogen chloride are produced in admixture by passing chlorine, methane, and hydrogen through a fluidized bed of inert solids at a temp of 325° to 450° C. The chlorine is added incrementally.

U.S.P. 2,585,478 (U.K. 13.1.49; 12.2.52). N. Levy, assr to Imperial Chemical Industries Ltd. Ethylene oxide is produced by reacting, at a temp of 150° to 400° C,

ethylene and oxygen in presence of a catalyst consisting of silver oxide mixed with 0·5 to 50% of powdered, fused silica or quartz.

U.S.P. 2,585,479 (U.K. 13.1.49; 12.2.52). N. Levy, assr to Imperial Chemical Industries Ltd. As in U.S.P. 2,585,478, except that the powder mixed with the silver oxide has a particle size of less than 100μ. Also the powder may be a silicate.

U.S.P. 2,585,483 (U.K. 13.1.49; 12.2.52). F. C. Mawer, assr to Imperial Chemical Industries Ltd. As in U.S.P. 2,585,478, except that the catalyst is a mixture of silver oxide and 0·5 to 50% of fused sodium aluminium silicate.

U.S.P. 2,585,506 (21.6.48; 12.2.52). E. C. Shokal, de L. E. Winkler, and P. A. Devlin, assrs to Shell Development Co. High mol wt. halogenated hydrocarbons are stabilized by addition of 2 to 5 wt-% of a liquid polymer of alkyl glycidyl ether. The polymer contains at least three epoxide groups per molecule.

U.S.P. 2,585,644 (25.11.46; 12.2.52). R. D. Fowler, W. B. Barford, and H. C. Anderson, assrs to the United States of America as represented by the U.S. Atomic Energy Commission. The hydrogen atoms of a petroleum lubricating oil are substantially completely replaced by fluorine atoms by heating the oil with bismuth pentafluoride at 90° to 450° C and separating the hydrogen fluoride produced.

U.S.P. 2,585,723 (13.7.50; 12.2.52). F. W. Banes, W. P. Fitzgerald, and J. F. Nelson, assrs to Standard Oil Development Co. Saturated aliphatic carboxylic acids are made by reacting acetic acid with ethylene in presence of di-tertiary butylperoxide at 145° to 170° C and under a pressure of 800 to 1000 p.s.i.

U.S.P. 2,585,816 (1.6.50; 12.2.52). J. K. Mertzweiller, assr to Standard Oil Development Co. Oxo alcohols are purified by contact with mercury, copper, or nickel at 25° to 180° C.

U.S.P. 2,586,128 (20.6.50; 19.2.52). F. T. Wadsworth, assr to Pan American Refining Corpn. Phthalic anhydride is made by vaporizing a bicyclic nonyl hydrocarbon, mixing the vapour with air and passing the mixture over a solid oxidation catalyst at 290° to 420° C.

U.S.P. 2,586,602 (7.8.47; 19.2.52). S. B. Beddow, assr to Standard Oil Development Co. *Iso*propanol is made by absorbing propylene in sulphuric acid, hydrolysing with water, steam distilling to obtain an *iso*propanol distillate containing 65 to 70 vol-% of *iso*propanol, diluting the distillate with water until it contains 65 to 80 vol-% of water, separating the oily layer, and finally stripping the *iso*propanol from the aqueous layer.

U.S.P. 2,586,694 (23.8.48; 19.2.52). H. O. Mottern, assr to Standard Oil Development Co. Aliphatic alcohols are dehydrogenated to carbonyl compounds by means of a catalyst comprising zinc, magnesium, or beryllium oxide, zirconium, cerium, or thorium oxide, and silicon, iron, or aluminium oxide.

U.S.P. 2,586,729 (7.12.50; 19.2.52). H. J. Shmidl, assr to Standard Oil Development Co. Sulphuric acid sludge from an alkylation process is heated to 280° to 325° F, neutralized with ammonium hydroxide, separated from carbonaceous materials and the ammonium sulphate isolated.

U.S.P. 2,586,780 (18.8.49; 26.2.52). F. W. Breuer and D. T. Zentmyer, assrs to Armstrong Cork Co. Bleached montan wax is converted to a hard waxy material by partially esterifying with a dihydric alcohol and completing the esterification with a higher polyhydric alcohol.

U.S.P. 2,586,780 (27.3.48; 26.2.52). R. L. Heider, assr to Monsanto Chemical Co. In the catalytic oxidation of ethylene to ethylene oxide in presence of silver, trisubstituted organic phosphates are added to the reaction. J. M. S.

Coal, Shale, and Peat

2487. Vacuum retorting of oil shale in a fluidized bed. J. W. Pringle, P. L. Barrick, and N. F. Wigton. *Industr. Engng Chem.*, 1952, **44**, 1489–91.—Apparatus, procedure, and results obtained are reported for an investigation of the vacuum distillation of oil shale using a fluidized bed. E. J. C.

2488. Relationship and practical application of results from the laboratory and practice. D. Refractory structural coke oven materials. E. The raw gas and its components. F. Ammonia water, ammonium sulphate, crystallization, and solution associates. W. Mantel and H. Hansen. *Brennstoff-Chem.*, 1952, **33** (5–6), 69–75; 75–80; 80–9. (*Head lab report, Harpener Mining A.G., Lünen.*)—This work covers many years. Section D deals with raw materials, production, and properties of chamotte, quartz-chamotte, and silica bricks. Composition, variations in behaviour, and factors affecting stability are discussed. Information regarding cryst structure, pore distribution, and operational stability is provided by photomicrographs of thin sections in polarized light. Instructions and essential val for coke oven bricks are tabulated.

Section E deals with coking coals, the yields of hydrocarbons and volatile components. Scattered val are tabulated for the composition of the raw gas after leaving the furnace. Recovery and treatment of by-products by condensation, washing, and purifying processes are described. The removal of H_2S from gas mixtures by irradiation with U.V. light is discussed and the results tabulated.

Section F deals with the composition of the ammonia water in relation to controlling factors. NH_3 compounds are listed as decomposable by steam or by milk of lime. Formulæ are developed for calculation of steam requirements in the still. Theoretical and practical principles governing production of pure white cryst $(NH_4)_2SO_4$ and the effect of associated compounds are considered. Numerous tables, photomicrographs, and diagrams are presented. R. T.

2489. Patent. U.S.P. 2,586,703 (1.11.46; 19.2.52). W. W. Odell, assr to Standard Oil Development Co. Method of producing hydrocarbons from carbonizable materials, such as shale, in a fluidized condition. J. M. S.

Miscellaneous Products

2490. Electron microscope study of plasticized latices. E. B. Bradford. *J. appl. Phys.*, 1952, **23**, 609.—The technique of making silicon monoxide replicas of the surfaces of air dried films is described. Particular study was made of films cast from Saran latex diluted with varying amounts of plasticizer. It is shown that the quality of the film depends upon the state of the particles, poor films consisting of discrete individual particles, whereas in a continuous transparent film the particles have coalesced into a polymeric mass. Replicas of surfaces of films of polystyrene and polyvinyltoluene before and after plasticizing are also shown. L. G. H.

2491. Patents. U.S.P. 2,583,588 (8.6.49; 29.1.52). J. C. Mosteller. A hydraulic medium of low inflammability comprising 15 to 25% mono-chloro trifluoroethene polymer, 35 to 45% of a paraffinic/naphthenic fraction, 7 to 13% of a liquid, oil-soluble dioctyl methylmethacrylate polymer, 6 to 10% white lub oil, and 25 to 35% of 2 : 6-di*tert*butyl-4-methylphenol.

U.S.P. 2,583,638 (15.2.49; 29.1.52). E. M. Evans and J. E. S. Whitney, assrs to British Resin Products Ltd. Copolymers of a vinyl phenol compound with *cyclo*pentadiene, indene, or coumarone.

U.S.P. 2,583,744 (5.4.48; 29.1.52). G. Schrader and H. Kükenthal, assrs to Farbenfabriken Bayer. Thiophosphoric esters having pesticidal properties. R. C. R.

2492. Patents. U.S.P. 2,584,126 (27.10.47; 5.2.52). W. E. Hanford, assr to E.I. du Pont de Nemours & Co. Copolymers of ethylene and dichlorodifluoroethylene containing 5 to 81% of the latter component.

U.S.P. 2,584,306 (1.2.50; 5.2.52). C. W. Theobald, assr to E.I. du Pont de Nemours & Co. Ethylenically unsaturated compounds are polymerized by contacting with a diazosulphone having the azo group directly attached to the sulphone group.

U.S.P. 2,584,315 (20.5.48; 5.2.52). R. J. Agnew, assr to The Texas Co. A copolymer of *ca* 30% by wt of the diallyl ester of 4-chloro-1 : 2 : 3 : 6-tetrahydrophthalic acid and *ca* 70% by wt of an unsaturated polyester formed by esterification of ethylene glycol with an equimolecular mixture of maleic anhydride and phthalic anhydride.

U.S.P. 2,584,316 (29.12.48; 5.2.52). R. J. Agnew, assr to The Texas Co. A copolymer of 30% by wt of diallyl endomethylenetetrahydrophthalate and 70% by wt of an unsaturated polyester formed by esterification of ethylene glycol with an equimolecular mixture of maleic anhydride and phthalic anhydride.

U.S.P. 2,584,334 (10.6.50; 5.2.52). E. Da Fano, assr to John B. Pierce Foundation. A composition having a high b.p., low m.p., and exceptional heat stability, and useful as a heat transfer medium, is a mixture of phenyl-, diphenyl-, and mixed phenyl–diphenyl- orthosilicates in such proportions that it contains 0·4 to 3·6 diphenyl radicals and 3·6 to 0·4 phenyl radicals for each silicate radical.

U.S.P. 2,584,413 (30.6.48; 5.2.52). M. E. Baer and L. E. Concannon. A cleaning and polishing composition is an oil-in-water emulsion comprising an oil phase consisting of 0·5 to 15% silicon oil and 75 to 10% volatile hydrocarbon solvent, 24·5 to 75% water, and 0·1 to 12% cationic emulsifying agent.

U.S.P. 2,585,359 (11.12.48; 12.2.52). R. R. Whetstone and T. W. Evans, assrs to Shell Development Co. Composition comprising nitrocellulose and a permanently fusible copolymer of a mixture of a diallyl ester of a dicarboxylic acid and an allyl ester of a saturated fatty acid.

U.S.P. 2,585,806 (9.10.46; 12.2.52). C. Mack, assr to Standard Oil Development Co. A flexible and elastic building composition comprises a fibrous material bonded with 10 to 90% of a blend of an aluminium soap of a fatty acid in an oil having a visc of 180 to 3000 S.S.U. at 210° F, said blend having a soft. pt. of at least 160° F.

U.S.P. 2,585,884 (4.10.48; 12.2.52). R. R. Whetstone and de L. E. Winkler, assrs to Shell Development Co. Triesters derived from a monocarboxylic acid of 5 to 15 carbon atoms and 1 : 2 : 6-hexanetriol or an alkyl substituted 1 : 2 : 6-hexanetriol.

U.S.P. 2,586,070 (3.11.47; 19.2.52). D. B. Luten and A. De Benedictis, assrs to Shell Development Co. 2 : 4-dimethyl-6-*tert*-butyl phenol (I) is made from mixtures of xylenols containing 2 : 4-xylenol (II) by mixing such mixture with (I) to form an addition product of (I) and (II), separating the addition product from the other components of the mixture, butylating the addition product to form (I), and recycling a portion thereof to form more addition product.

U.S.P. 2,586,124 (Netherlands 12.6.47; 19.2.52). G. J. van Amerongen, assr to Rubber-Stichting. Aqueous dispersions of chlorinated rubber are made by stabilizing a latex of a conjugated diolefin rubber with 2 to 10 wt-% of a water-soluble salt of a quaternary ammonium base or of a tertiary amine, acidifying with strong mineral acid and passing chlorine through the acidified latex at 0° to 100° C.

U.S.P. 2,586,357 (30.6.50; 19.2.52). W. E. Llewellyn, assr to E.I. du Pont de Nemours and Co. Pressure-coalescing composition comprising tetrafluoroethylene polymer particles of colloidal size mixed with a hydrocarbon having a visc of at least 0·45 cp at 25° C and a m.p. $<100°$ C.

U.S.P. 2,586,571 (U.K. 17.2.48; 19.2.52). J. J. Sleightholme, assr to The Sherwin-Williams Co. Copolymers made by heating styrene with an aromatic extract obtained from lubricating oils by the Edeleanu process. A higher fatty acid may be present.

U.S.P. 2,586,572 (U.K. 17.2.48; 19.2.52). J. J. Sleightholme and T. C. Hammond, assrs to The Sherwin-Williams Co. Copolymers made by heating styrene with an aromatic extract obtained from lubricating oils by the Edeleanu process and with a mixed ester of a polyhydric alcohol containing unsaturated drying oil fatty acid radicals.

J. M. S.

Corrosion

2493. Corrosion control. Anon. *Oil Gas J.*, 23.6.52, **51** (7), 109.—No. 4 in this series concerns protection of storage tanks. Installation of reinforcement and application of gunite are described. G. A. C.

2494. Corrosion control. Anon. *Oil Gas J.*, 30.6.52, **51** (8), 115.—Experience with gunite linings is given, illustrations showing lining after six years' service and condition of crown sheet of tank after removal of protective coating. G. A. C.

2495. Gasoline resistant tank coatings. W. W. Cranmer. *Corrosion*, 1952, **8** (6), 195–204.—The corrosion of mild steel in cargo tanks carrying gasoline is due primarily to ballast seawater, and is accelerated by the gasoline. After extensive laboratory tests three promising organic protective coatings were selected: (*a*) a proprietary combination of vinyl and polysulphide resins; (*b*) a proprietary vinyl resin material; and (*c*) a Saran-type material (a solution of vinylidene chloride/acrylonitrile copolymer in M.E.K.). These coatings are air-drying and are brush- or spray-applied to sand-blasted surfaces. Service tests showed that the Saran-type coating was most satisfactory; applied in several coatings to a thickness of 0·008 inch it afforded protection for four years. It can be touched up at successive four-year intervals to give protection indefinitely. Precautions are necessary in its application to avoid explosion risks. This form of protection is more effective than such other methods as inhibitors in the cargo and/or ballast, dry inert atmospheres, cathodic protection, and inorganic coatings.
K. G. B.

2496. Vinyl coatings protect marine installations from the ravages of corrosion. H. E. Waldrip. *Oil Gas J.*, 16.6.52, **51** (6), 291.—An extensive review on the use of vinyl acetate, vinyl chloride acetate, and vinyl butyral resins for protection of drilling, cargo, and boiler barges in service in the Gulf of Mexico. Composition of the resins, preparation of steel surfaces before coating, accelerated laboratory tests, coating specifications, application, and performance are dealt with. Tables give salt-fog cabinet and fresh-water bath tests, and field inspection of coated barges and data on three barges coated with marine paint.
G. A. C.

2497. Intergranular failure of stainless steel heater tubes. G. A. Works. *Corrosion*, 1952, **8** (6), 217–21.—Heater tubes of Type 316 steel (16% Cr, 13% Ni, 3% Mo) in a phenol solvent plant failed after ten years' service at a max wall temp of 750° F. The heating had caused carbide precipitation at grain boundaries, and thereby sensitized the metal to intergranular corrosion and cracking. Affected tubes were reclaimed before cracking by heating at 1600° F for 24 hr, and have subsequently given satisfactory service for twenty-four months.
K. G. B.

2498. Titanium. Anon. *Ingenieur*, 4.7.52, **64** (27), Ch69–70.—The physical, chemical, and mechanical properties of this modern material are given, as well as its machining, welding, and alloying possibilities. A table giving the corrosion stability for thirty-nine different chemicals at different concentration and temp is included. An extensive paper by H. O. Nicolaus, "Titan und Titan-legierungen" in the journal *Werkstoffe und Korrosion* Sept. 1951, pp. 321–34, and Nov. 1951, pp. 416–24, is referred to.
G. F. T. C.

2499. Patents. U.S.P. 2,584,623 (6.5.47; 5.2.52). W. H. Schneider. A method of protecting buried pipes against electrolytic corrosion is described. It involves establishing an electric potential along the pipeline relatively negative to the potential of the earth in which the pipeline is buried.

U.S.P. 2,586,323 (27.5.48; 19.2.52). W. F. Glassmire and W. R. Smith, assrs to The Texas Co. Corrosion of metal vessels in which hydrocarbons are reacted in presence of an aluminium chloride–hydrocarbon complex liquid catalyst and hydrogen chloride, is prevented by incorporating in the catalyst 0·2 to 2·0% by wt of iodine, hydrogen iodide, or a hydrocarbon iodide.

U.S.P. 2,586,709 (3.8.49; 19.2.52). C. Phillips, assr to Standard Oil Development Co. The corrosion of copper containing alloys in the presence of aqueous solutions of ammonium salts is reduced by adding an alkali metal salt of an oil-soluble petroleum sulphonic acid to the solutions.
J. M. S.

Engines and Automotive Equipment

2500. The new B. and W. turbocharged engine. Anon. *Motor Ship*, June 1952, **33** (387), 88.—A description of this engine, with preliminary results of tests, was previously given (*see* Abs. No. 330). It is a two-stroke exhaust-gas turbo-charged poppet-valve engine, of 740 mm cylinder dia and 1600 mm stroke. Final tests have been run with

turbo-chargers only, and without the chain-driven positive displacement blowers. Both engine and turbo-charger performance had been entirely satisfactory at all speeds and loads. Starting from cold has been as reliable as with chain-driven blowers; the starting air gives the turbo-chargers a considerable initial speed, which instantly increases with engine load and revolutions. Normal output for the turbo-charged engine, for continuous service, is 1250 b.h.p/cyl at 115 r.p.m. (m.i.p. = 8·0 kg/sq. cm.), while that for the non-turbo-charged engine is 920 b.h.p. at 115 r.p.m. (m.i.p. = 6·5 kg/sq. cm.). Thus there is an increase in output of 35%. Fuel economy has been further improved, and consumptions below 150 g/b.h.p/hr have been recorded; the max firing pressure has not been increased, and is maintained at about 50 kg/sq. cm.

The engine is to be installed in a 17,000-ton tanker; it has been decided to run the engine with turbo-chargers only, maintaining the existing Roots blowers as emergency units disconnected from the chain drive.

Other turbo-charged engines are under construction or on order. Advantages of this system over the existing non-supercharged engines are: (*a*) the possibility of increasing the output for single-acting, single-screw installations to 15,000 to 17,500 b.h.p.; (*b*) a reduction in fuel consumption of about 6% is obtained; (c) space requirements are less, length of engine for same output is reduced by about 20%; and (*d*) reduction in wt is about 25%. U. M.

2501. Chain-driven pumps for Doxford engines. Anon. *Motor Ship*, June 1952, **33** (387), 105.—An arrangement whereby rotary pumps for the main engine forced lubrication, fresh water cooling and salt water circulating pumps will be chain-driven off the propeller shafting has been developed by the Furness Shipbuilding Co. and Messrs. Trewent and Proctor in conjunction with Stothert and Pitt Ltd. The arrangement is designed to dispense with the use at sea of electricity driven pumps, which demand greater generator capacity, or the employment of steam-driven reciprocating pumps for these services. The pumps, of the positive screw-displacement type, are chain-driven through clutches and increasing gear from the propeller shaft, which runs normally at 115 r.p.m. The speed is increased to 740 r.p.m. for all pumps. It is thought that the use of these pumps will result in economies in fuel and maintenance costs. U. M.

2502. New Admiralty range of diesel engines. Anon. *Motor Ship*, June 1952, **33** (387), 119.—The engine adopted by the Admiralty for the Standard Range II, covering 200 to 800 b.h.p., is the Paxman V-type, four-stroke unit designated YHA. It is basically similar to the RPH series, but uses light alloy for many of its major components, including crankcase, cyl blocks, and cyl heads. Engine, designed for either marine propulsion or auxiliary duties, has a cyl bore of 7 inches, stroke of 7½ inches, and, although designed for 1500 r.p.m., will run in most cases at 1000 r.p.m. Power range extends from 200 b.h.p. (12-hr rating of the six-cyl normally aspirated engine) to 800 b.h.p. with a twelve cyl supercharged engine running at 1250 r.p.m. The b.m.e.p. of former engine is 79 p.s.i. and of the twelve-cyl supercharged engine, 120·5 p.s.i. Mechanical efficiency stated to be 81 to 82% and fuel consumption about 0·35 lb/b.h.p/hr. At a b.m.e.p. of 120 p.s.i. exhaust temp is 740° F. Overall length when pressure-charged 7 ft 10 inches, when normally aspirated 7 ft 5½ inches. Dual fabric filters are fitted into fuel system to de-aerate the fuel prior to delivery to the block-type fuel pumps. U. M.

2503. Krauss-Maffei KMD6 engine. F. Sass and P. H. Schweitzer. *Auto Engr*, July 1952, **42** (555), 252.—The engine described is a 90° V-four, loop-scavenged, two-stroke diesel unit, with a two-throw crankshaft, designed for road vehicles. It develops 145 continuous net h.p. at 2200 r.p.m. or intermittently 160 h.p. at 2300 r.p.m. Overall dimensions are: length 35 inches, width 36 inches, height 44 inches, and weight with all accessories is 1570 lb (10·9 lb/h.p.). Cyl dimensions are 120 mm × 130 mm. The crank-case is a one-piece iron casting, and the cylinders are individual castings with integral cooling passages. Silicon-aluminium heads are used. The Bosch fuel injectors have Deckel six-orifice nozzles opening at 3000 p.s.i. Further design features are given. Comprehensive performance data are listed and performance and characteristic curves supplied. In most of the operating range the specific fuel consumption does not exceed 0·36 lb/b.h.p/hr. Road tests of the engine were carried out. T. T.

2504. Large American diesel and dual fuel stationary engine. Anon. *Gas Oil Pwr*, 1952, **47**, 136–8.—These two-stroke engines are built as six, eight, or ten-cyl units, with cyl dimensions 18 inches bore and 27 inches stroke. Operating at 277 r.p.m., equivalent to a b.m.e.p. of 72·8 p.s.i., they develop 2100, 2800, and 3500 b.h.p. respectively, with a piston speed of 1246 ft/min.

The piston is built in two parts, and the head contains the concave combustion chamber. The piston is fitted with five pressure rings above the gudgeon pin, and one pressure and two scraper rings below. Lub oil under pressure is circulated by a motor-driven pump from an oil header to main and crankpin bearings. Special provision is made for an adequate supply of cooling oil to the piston crown.

The method of starting, both with oil fuel and with dual fuel, is described.

H. C. E.

2505. Gas turbine locomotive performance and efficiency tests. Anon. *Gas Oil Pwr*, 1952, **47**, 128.—The results of four tests under operating conditions of the W.R. locomotive No. 18,000. The data are arranged in a table containing thirty-eight items. (*See also* Abs. No. 1739.) H. C. E.

2506. Lister freedom engines. Anon. *Gas Oil Pwr*, 1952, **47**, 125–7.—These engines are built as two-, three-, four-, and six-cyl units developing 9 b.h.p/cyl at 1800 r.p.m., and a single-cyl unit developing 8 b.h.p. at 1500 r.p.m. Cyl bore and stroke are 3·75 and 4·5 inches respectively, giving a swept volume of 810 cc/cyl.

Al-alloy pistons carry three compression and two scraper rings. The spheroidal combustion chamber is fitted with a spring-loaded lever so that the C.R. can be increased to 24 : 1 when starting, from the normal value of 20 : 1. Details of engine construction are given.

The auxiliary components are grouped together at one end of the engine. A gear-type lub oil pump delivers oil to the main gallery, from which it passes to the main working parts. An impeller-type pump circulates cooling water at a min rate of 250 gal/hr/cyl. A spiral fuel filter and an induction air cleaner are fitted. H. C. E.

2507. Northern Ireland railcar conversion. Anon. *Gas Oil Pwr*, 1952, **47**, 133–5.—A train comprising four powered coaches with eight engines and two non-powered coaches, weighing 185 to 225 tons, can attain a speed of 73 m.p.h. It can be used in smaller combinations if required.

The engines are Leyland horizontal diesel units developing 125 b.h.p. and have six cyl each of 4·8 inches bore and 5·5 inches stroke. They are mounted longitudinally side-by-side under the floor, and the drive from each is taken through a Lysholm–Smith gearless torque convertor to an auxiliary gearbox and to the inside axles of the bogies. The front end of the engine carries a shaft for compressor and generator. Details of the control mechanism, safety devices, and auxiliary equipment are given.

H. C. E.

2508. Patents. U.S.P. 2,586,789 (17.2.48; 26.2.52). W. W. Cushman. Water is injected into fuel entering an I.C. engine by means of pressure from a combustion chamber of the engine.

U.S.P. 2,587,060 (2.3.46; 26.2.52). H. R. Meyer. Apparatus for lubricating I.C. engines. J. M. S.

Safety Precautions

2509. How to achieve an enviable safety record. A. T. van Pelt. *Oil Gas J.*, 21.4.52, **50** (50), 119.—Berry Asphalt Co, Magnolia, Arkansas, have a record of three and a half years without a lost-time accident of any kind. A safety programme was initiated as a result of accidents a few years ago, and over 100 production workers attend meetings. G. A. C.

2510. How Norco engineers solved the problem of (1) gas freeing of tanks, (2) oil freeing waste water. R. G. Stillinger and B. S. Graves. *Oil Gas J.*, 16.6.52, **51** (6), 279.—Method is described for rapid and complete removal of hydrocarbon vapours from

storage tanks by drawing gas from bottom of tank whilst using water to wet all inside surfaces at Norco refinery of Shell Oil Co.

A relatively inexpensive method of oil freeing waste water by installation of clean oil recovery sumps in several operating areas is depicted and described. G. A. C.

2511. New fuel safety system for two-cycle gas engines. H. L. Ingram. *Oil Gas J.*, 16.6.52, **51** (6), 230.—A method is described to eliminate the hazard of an explosion of gas and air mixture caused by leakage past cyl rings into crankcase or air system of two-cycle gas engines under certain conditions at opening of ignition switch. The installation is at Agua Dulce, Texas, compressor stations of Tennessee Gas Transmission Co. G. A. C.

MISCELLANEOUS

2512. Persian oil dispute at the International Court. Anon. *Petrol. Times*, 27.6.52, **56**, 543.—The proceedings which opened at The Hague on June 9, 1952 are reported. G. A. C.

2513. Influence of cyclical variations in overall business conditions upon the demand for petroleum products. H. Schwall, R. D. Bodig, and E. B. Slade. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 97.—An attempt is made to analyse statistically the influence of such factors as national production and/or national income, together with other important trends upon the deviations from the normal of the demand for petroleum products. D. K.

2514. Past, present and likely future price structure for the international oil trade. W. J. Levy. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 112.—The price structure of the international oil trade before and after the second world war and the likely future world oil price structure is discussed. D. K.

2515. Distribution of oil throughout the world. J. Oliveira da Silva. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 133.—The joint effort of all nations whether oil producing or not for the expansion of production, elimination of discriminatory treatment in commerce, and the reduction of economic barriers is advocated now as it was by President Roosevelt in 1944. D. K.

2516. Relative economic position of petroleum and synthetic oil. An analysis of the supply–demand position of these fuels. E. Ospina-Racines. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 142.—The principal factors governing oil supply, replacement costs, crude oil price, capital requirements, and net return, as well as oil demand, are discussed. It is concluded that petroleum is due to occupy first place as a low-cost liquid fuel for the immediate and remote future. D. K.

2517. Use of statistics as an aid to management in the petroleum industry. W. J. Harrison. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 135.—The types of statistical activity desirable are recordings of a company's own activities, provision of an economic background, and mathematical analysis of data. These are discussed. The organization of statistical services in a large firm are described. D. K.

2518. Canadian oil consumption rose 14 per cent in 1951. Anon. *World Petrol.*, 1952, **23** (5), 76–7.—Average Canadian demand for pet products increased from 357,800 b.d. in 1949 to 410,700 b.d. in 1951; crude oil production rose from 78,400 to 130,500 b.d. Greatest increase in demand was for middle dist 22,000,000 brl in 1949 to 35,000,000 brl in 1951. Data are tabulated showing road-vehicle registrations, pet supply and demand, and progress towards self-sufficiency, 9·4% of the 80,968,000 brl required in 1946 and 32·6% of 150,400,000 brl in 1951 being indigenous. E. B.

2519. Petrochemistry in Canada. Anon. *World Petrol.*, 1952, **23** (5), 72–5.—Description of petrochemical plants, their capacity and location. Included are Montreal plants for producing 20,000,000 lb p.a. *iso*propyl alcohol and acetone; ethylene glycol

and ethylene oxide; 13,000,000 lb phenol and 8,000,000 lb acetone from cumene via cumene hydroperoxide. S recovery plants operating on sour gas at Jumping Pound and Turner Valley to produce 10,000 tons p.a. are described more fully and flow diagrams given. E. B.

2520. Active studies of Athabaska oil sands undertaken by seven oil companies. R. S. Knowles. *World Petrol.*, 1952, **23** (5), 106–7.—Five independent Canadian companies plan to core drill thirty-five holes on each of five 50,000-acre leases. Two U.S. companies have also leased areas. Rentals are 5c, 10c, and 25c/acre over first three years. Exploitation rental will be 1$/acre with $\geq 10\%$ royalty. Swedish company is to experiment at Government plant at Bitumount on process understood to involve vaporization by an electrical method. E. B.

2521. The Gulf Coast to-day. F. L. Resen *et al.* *Oil Gas J.*, 16.6.52, **51** (6), 190.—A special twenty-page section is given on Gulf Coast petroleum activities, including petrochemistry, refining, natural gas and gas pipelines, crude oil production, development and exploratory drilling, crude oil and product lines. G. A. C.

2522. United Kingdom petroleum trade in May and the five months. Anon. *Petrol. Times*, 11.7.52, **56**, 581.—Import and export figures of petroleum products for the United Kingdom are given. A threefold increase in oil exports of domestic origin is shown. G. A. C.

2523. Oil and the oil industry in French economy. I. Part played by petroleum products in French economy. R. Navarre. *Rev. Inst. franç. Pétrole*, 1952, **7**, 143–50.—Although 90% of pet products used in France are for power generation or uses ancillary thereto, only 25% of French power requirements are met by pet. Increase in *per capita* power consumption in France is highly desirable, and pet is best means of obtaining such additional power. Taking 1938 as datum year, use of fuel oils has increased by a factor of 3 whilst that of engine fuels by 1·2. Although agricultural pet consumption has risen 10·4 times, *per capita* production of French agriculture is one-third that of the U.S.A., which, on an equal area basis, has three times as many tractors using six times as much fuel. V. B.

2524. Productivity through concentration of means. C. G. Deutsch. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 167. (In French.)—The present legal system in France favours concentration of means rather than commercial independence in the petroleum industry, and at present this gives increased productivity. D. K.

2525. Refining margin in France and treatment costs in French refineries. A. Martin, R. Granier de Lilliac, and A. Giraud. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 152. (In French.)—An attempt to isolate the most important economic factors affecting the refining margin in France has been made. Refining profits, the difference between the margin and costs of treatment, depend on a number of economic and technical factors in connexion with which a number of problems facing French refiners are considered. D. K.

2526. Economic and financial problems of Italian hydrocarbon gases. 1. State concessions and state participation. 2. Private or state management. M. Boldrini. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 38.—In Pt I the economic and financial aspects of the gases in Italy are discussed from a theoretical standpoint. It is concluded that given the existence of state rights to products of the sub-soil, the youth of the hydrocarbon industry and the already large investments made by the state, direct state management is the most suitable form of exploitation.

In Pt 2 the points in favour of state monopolization, with particular reference to the Po deposits, are considered from a local viewpoint. A survey is given of the production and requirements of natural gas. D. K.

2527. Petroleum and technical aid. H. Ballande. *Bull. Ass. franç. Tech. Pétrole*, 1952 (93), 3–14.—Account of mission to the U.S.A. under ægis of OEEC to study search and production. Aid, in pet field, given to France during 1948–51 inclusive

amounts to $538·5 million (85% as gift). Causes for greater pet search activity in the U.S.A. as compared to France are reviewed; beneficial tax legislation and availability of specialized suppliers for drillers' needs are among the more important.
V. B.

2528. Significance of the Marshall Plan for the petroleum industry in Europe. Historical review of the period 1947–1950. E. Groen. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 58.—The origins of the Marshall Plan and the developments of organizations associated with the plan in Europe and the U.S. are described. The way in which petroleum and its products have been dealt with in the Marshall Plan is discussed. D. K.

2529. Survey of mineral oil supply position of the Federal [German] republic and adjoining European countries. W. Karsten. *Erdöl u. Kohle*, 1952, **5**, 321–3.—German crude production for 1952 is estimated at (all figures in 000s tons) 1367 and 2089 for 1955, imports were 303 for 1948 and forecast as 6000 for 1954. Proportion of Middle East oil was 30% in 1948 and 84% in 1951. Proportion of imported gasoline + diesel fuel fell from 71·3% in 1948 to 11·4% in 1951. Requirements of various grades of pet products are tabulated for 1951, 1952, 1957, total for latter year being 8800. At beginning of 1952 refining capacity was 6000. Scandinavia has refining capacity of 1400 with consumption of 7200, whilst Benelux group has refining capacity (9400 for 1952) in excess of consumption. V. B.

2530. A vocabulary of job and technical terms used in the petroleum industry. A. W. J. Mayer. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 211.—As a result of a resolution adopted by the Petroleum Committee of the International Labour Office, work has commenced on a vocabulary in English, French, and Spanish dealing with jobs, equipment, and machines. The difficulties encountered are discussed, and some proof pages are shown. D. K.

2531. Petroleum research in the independent, nonprofit laboratory. F. C. Croxton. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 218.—The reasons for industry's use of this type of laboratory, which occurs mainly in the U.S., are examined as they apply to petroleum investigations. Some particular projects are described. D. K.

2532. A practical approach to employee training. R. W. Faulk and H. K. O'Gara. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 182.—The experience of the Shell Oil Co. in the field of employee training during the last fifteen years is discussed. Five types of training are particularly considered, *i.e.*, induction, job, supervisory, graduate, and executive. D. K.

2533. Training Esso men in Europe and North Africa. J. A. Barton. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 190.—The various aspects of training in Esso and affiliated companies is outlined. D. K.

2534. Training and improvement within the framework of an undertaking. J. Nocturne. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 201. (In French.)—The part played by training in a French petroleum company, the Standard Française des Pétroles, is discussed. The aspects considered are: selection of personnel, its orientation and instruction; technical or specialized training; general training; and organization within the undertaking. D. K.

2535. Problems of classification and documentation in the United States Patent Office in the field of petroleum and allied subjects. M. F. Bailey, B. E. Lanham, and J. Leibowitz. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 13.—The specialized classification system used in the U.S. Patent Office is described. Various types of searches are explained to illustrate the need for the type of system developed. Specific classes of subject matter are considered to show how all documents relating to and of interest to the petroleum industry are brought together. The use of machine equipment to perform patent researches for compositions of matter in terms of ingredients and functions or both is also described. D. K.

2536. Modifications since 1937 to the legal statutes concerning exploration for hydrocarbons in metropolitan France and other countries of the French union. J. Deveaux-Charbonnell. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 23. (In French.)—Modifications of the legal statutes governing exploration for hydrocarbons in metropolitan France and other countries of the French union have been made, since 1937, with a view to encouraging prospecting by private concerns. D. K.

2537. The use of machine-sorted punched cards in documentation. B. Brown Porter and G. S. Crandall. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 1.—A punched card system of documentation is described and the advantages listed. D. K.

2538. Modern petroleum processing. G. H. Weber. *Proc. 3rd World Petrol. Congr.*, 1951, **4**, 308–14.—The history of gasoline production is outlined, and the future trend towards greater use of heavier distillate and residual fuels is foreshadowed.

Modern refining processes are classified into separation processes, of which solvent extraction and adsorption are described; and conversion processes, of which catalytic cracking and reforming gas conversion, alkylation, and polymerization are outlined. D. H.

2539. Composition of United States and some foreign crude oils. H. M. Smith. *Proc. 3rd World Petrol. Congr.*, 1951, **6**, 319–35.—A statistical study of the following properties of U.S. crudes is made: sulphur, visc, asphalt, naphtha and gas oil, % aromatics and paraffins, plus naphthenes in the naphtha and gas oils, and proportion of naphthene ring and paraffinic chain in the paraffin–naphthene chain. The data are considered under eight geographical divisions, and are presented in terms of percentage of crudes produced falling within selected limits. 330 fields are covered, representing about 65% of total crude production.

Additional data on Middle East and South American crudes are discussed. D. H.

2540. API refining division committees report on their 1951 activities. *Petrol. Process.*, May 1952, **7** (5), 620–31.—Reports on work carried out during 1951 by the various technical committees of the API Division of Refining are presented by the committee chairmen. The reports are: Refinery equipment, W. H. Creel; Analytical research, E. L. Baldeschwieler; Training, T. M. Rushing; Automotive research, J. T. McCoy; Petroleum products, A. E. Miller; Disposal of refinery waste, R. N. Giles. D. W. F.

2541. Is specialized engineering needed? E. F. Gibbons. *Petrol. Process.*, May 1952, **7** (5), 615–19.—To determine whether a specialized petroleum refinery engineering undergraduate course is more, or less, desirable than a general chemical engineering course, *Petrol. Process.* staff have obtained and presented the opinions of leading academic personalities from schools both with and without the specialized course. D. W. F.

2542. Petroleum and rubber. E. de Meeus. *Bull. Ass. franç. Tech. Pétrole*, 1952 (93), 51–63.—Inter-relationship of the two industries is considered. Main pet products used in rubber industry are C black and oils for regeneration and extension. Latter use is a new factor, on basis of addition of 33% pet oils to synthetic and 10% to natural rubber possible annual consumption is 500,000 tons. Extender oil characteristics and uses are considered, solvent extracts are frequently used. For 1951 pet products used in rubber industry amount to 1·8 million tons, approx equal to quantity of natural rubber produced. Distribution of such products is (000s tons): synthetic rubber, 950; C black, 750; extender oils, 30; regeneration oils, 40; blending oils, wax, etc., 55. V. B.

2543. Economic use of roads. C. T. Brunner. *Proc. 3rd World Petrol. Congr.*, 1951, **10**, 174.—The links between the petroleum industry and roads and the vehicles using them are discussed. D. K.

2544. Combustion turbines. Power, traction and marine applications. M. Widmer. *Bull. Ass. franç. Tech. Pétrole*, 1952 (93), 15–49.—Thermodynamics of the turbine cycle (closed and open) and the efficiencies obtained are considered and schematic

flow diagrams given. Plant layout and construction of the various turbine parts is described. For power production main advantage of turbine installation over steam plant is much smaller water requirement and more rapid start-up. At max efficiency (*ca* 35%) turbine running costs (using oil fuel) are approx same as boiler plant using coal. Numerous industrial power installations are described and illustrated, with particular reference to equipment manufactured by the Brown–Boveri Co. Turbines would be particularly suitable for pump drive on natural gas transmission lines. For pet refinery use absence of water treatment problems is big advantage; necessary process steam could be obtained from low-pressure boilers operated by turbine exhaust. Traction and marine uses are only briefly considered. V. B.

2545. Calculation of thick-walled cylindrical shells of carbon steel subject to internal pressure. W. P. Kerkhof. *Ingenieur*, 13.6.52, **64** (24), W38.—The author gives an explanatory drawing of the stress distribution in a thick-walled cyl. This follows on his article published under the same title in *De Ingenieur*, 2.5.52 (*see* Abs. No. 2001). G. F. T. C.

ADDITIONS TO THE LIBRARY

Comision Permanente del Asfalto—5th Annual Reunion, 1950. Buenos Aires, 1952, pp. 428.

A collection of twenty articles, with discussions arising therefrom, read before the Permanent Commission on Asphalt (Argentine Republic) at Buenos Aires in Dec. 1950. Subjects covered are mainly concerned with use of asphalts in roads and paving mixes, including white and coloured asphalt.

Financial Analysis of 30 Oil Companies for 1951. F. G. Coqueron. New York: Chase National Bank, 1952. Pp. 28.

Radioactive Atoms and Isotopic Tracers. Joseph W. Kennedy. Twenty-sixth Annual Priestley Lectures, The Pennsylvanian State College. State College, Pa.: The College, 1952. Pp. 89. $2.00.

In the five lectures which form the 1952 Priestley Lectures, the author, who is chairman of the Department of Chemistry at Washington University, St Louis, Missouri, dealt successively with: (i) nuclear transformations; (ii) uranium, fission, and transuranium elements; (iii) isotopic tracers and electron transfer reactions; (iv) quantitative kinetic studies with tracers; and (v) self-diffusion of aqueous ions.

ASTM Standards on Engine Antifreezes. ASTM Committee D-15. Philadelphia: American Society for Testing Materials, 1951. Pp. 36. $1.00.

Methods included cover sampling and preparing aqueous solutions of engine antifreezes; freezing point of solutions; physical tests for boiling point of engine antifreezes, and specific gravity of concentrated antifreezes by the hydrometer; chemical tests for ash content and reserve alkalinity of concentrated engine antifreezes, and for water in concentrated engine antifreeze by the iodine reagent method.

Specifications cover ASTM thermometers and hydrometer–thermometer field tester for engine antifreezes.

ASTM Proceedings 1951. Vol. 51. Philadelphia: American Society for Testing Materials, 1952. Pp. 1322 + x.

Institution of Mechanical Engineers. Proceedings. Vol. 164, 1951. London: The Institution, 1952. Pp. 509 + ix.

1952 SAE Handbook. New York: Society of Automotive Engineers, 1952. Pp. 946.

Many new standards and revisions of existing standards appear in this volume of SAE specifications, particularly in relation to steel, rubber, tubing and fittings, passenger cars and trucks, and tractor and similar equipment.

In the lubricants field there have been changes in the transmission- and axle-lubricant classification. A new oil SAE 75 is included with a max viscosity of 15,000 SUS, at 0° F and a non-channelling figure of −40° F. SAE 80 now has a minimum of 15,000 SUS at 0° F unless the viscosity at 210° F is not less than 48 SUS. SAE 90 is now classified at 210° F (75 to 120 SUS, the latter being waived if the 0° F figure is not less than 750,000 SUS, and non-channelling temperature is −10° F. The non-channelling figure for SAE 140 is +20° F, and there is no change in SAE 250.

Report of the Fuel Research Board, 1949–50. London: HMSO, 1951. Pp. 60 + vi. 2*s*. 6*d*. net.

This in the main is the report of the Director of Fuel Research and includes data on investigations into the Fischer–Tropsch synthesis, pulverized fuel problems, thermal decomposition of *n*-paraffins, the gasification of coal, etc.

Standard Practices for Stationary Diesel Engines. Chicago, Ill.: Diesel Engine Manufacturers Association, 1951. 4th Edn. Pp. 197.

Procedure Handbook of Arc Welding Design and Practice. Ninth edn. Cleveland, Ohio: Lincoln Electric Co., 1950. Pp. 1200. $2.50.

Lincoln's Incentive System. James F. Lincoln. New York: McGraw-Hill, 1946. Pp. 192. $2.00.

Selection of Oils for Carbureted Water Gas. E. S. Pettyjohn and H. R. Linden. Chicago: Institute of Gas Technology, 1952. Pp. 51. $4.00.

Selection of Oils for High-Btu Oil Gas. H. R. Linden and E. S. Pettyjohn. Chicago: Institute of Gas Technology, 1952. Pp. 48. $5.00.

These 16T Research Bulletins (Nos. 9 and 12 respectively) present data on the relationships of physical and chemical properties of gas-making oils with the enriching values and qualities and quantities of products. The yield estimates compared well with plant results.

THE INSTITUTE OF PETROLEUM

NOTICES, SEPTEMBER 1952

ENTRANCE FEES AND SUBSCRIPTIONS

The current Entrance Fees and Annual Subscriptions for membership of the Institute are :

	Entrance Fee	*Annual Subscription*
	£ s. d.	£ s. d.
Members and Fellows	2 2 0	4 4 0
Associate Members and Associate Fellows	1 1 0	3 3 0
Student Members	Nil	1 1 0

APPLICATIONS FOR MEMBERSHIP OR TRANSFER

The following have applied for admission to or transfer of membership in the Institute. In accordance with the By-laws, the proposals will not be considered until the lapse of at least one month after the publication of this *Journal*, during which time any Fellow, Member, Associate Fellow, or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of the candidate.

The object of this information is to assist the Council in grading the candidate according to the class of membership.

The name of candidates' proposers and seconders are given in parentheses.

Application for Membership

ACKER, James Frederick, maintenance engineer, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

AINSWORTH, Harland Basil, storage and export loading co-ordinator, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

ANDERSON, David, Major, R.A.S.C. (*P. F. Ellis*; *E. J. Horley.*)

BAXTER, Alexander Duncan, proofer of aircraft propulsion. (*C. S. Williams*; *D. T. A. Townend.*)

BERRIDGE, Stephen Arthur, assistant chief chemist, Esso Petroleum Co. Ltd. (*H. Jagger*; *J. McCallum.*)

BHATTACHARJEE, Nalini Kanta, process chemist, Assam Oil Co. Ltd. (*B. R. Fraser*; *P. F. Ellis.*)

BISHAI, Sobhi Giris, technical department, Shell Co. (Egypt) Ltd. (*A. D. Cooper*; *H. A. Blackmore.*)

BOSTOCK, Norman George, assistant engineer, Anglo-Iranian Oil Co. (*R. Stansfield*; *H. Eatwell.*)

DAVIES, Wilfrid Hillman, chief accountant, Esso Petroleum Co. Ltd. (*C. Chilvers*; *H. C. Tett.*)

D'SILVA, Arthur Nicholas Saturine, chemist, Bahrein Petroleum Co. Ltd. (*W. T. Barrett*; *N. B. Gibson.*)

EDWARDS, Raymond Montague, chief chemist, Permanite Ltd. (*D. C. Broome*; *V. L. Hope.*)

FINDLAY, James Steuart, drilling engineer trainee, Trinidad Leaseholds Ltd. (*W. T. Pickard*; *A. S. Curlet.*)

GLOVER, Daniel Mark, chairman and managing director, United Lubricants, Ltd. (*F. Dakin*; *W. Kay.*)

ISMAIL, Saad Hassan, technical department, Shell Co. (Egypt) Ltd. (*A. D. Cooper*; *H. A. Blackmore.*)

JAY, Percival Frederick Walter, terminal superintendent, British Controlled Oilfields Ltd. (*P. de Pass*; *R. Baker.*)

JOHNSTONE, Norman White, auditor, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

JONES, Meurig Davies, mud engineer, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

KUPPUSWAMI, Venkataraman, instructor, A.S.C. School. (*P. F. Ellis*; *E. J. Horley.*)

LEVORSEN, Robert Irving, resident manager, Dominion Oil Ltd. (*P. E. T. O'Connor*; *L. A. Bushe.*)

NEWLAND, George Edward Christopher, personnel officer, in charge wages and job evaluation, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

PITTAWAY, Gordon Singleton, assistant production maintenance engineer, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

RAMSDEN, Gerald Archibald Goldie, stillman (crude unit), Bahrein Petroleum Co. Ltd. (*A. P. Beauchamp*; *F. Turner.*)

ROSE, Maxwell Neville, in charge oil distribution, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

RYLANCE, Frederick Haywood, London manager, John Shaw Ltd. (*S. L. Witard*; *E. Jarman.*)

SHAW, Kenneth John, continuous stores auditor, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

STERN, Benjamin Alfred, petroleum consultant, Israeli Standardization Institute. (*R. B. Hobson*; *A. H. Chatwin.*)

SWAIN, Francis Alastair, bulk petroleum installator, R.A.S.C. (*P. F. Ellis*; *E. J. Horley.*)

TOMLINSON, George William, chemist, Esso Petroleum Co. Ltd. (*H. Jagger*; *J. McCallum.*)

VAUGHAN, Dennis Arthur, plant surveyor, Kent Oil Refinery Ltd. (*F. A. Maliphant*; *N. W. Grey.*)

WARD, George, assistant engineer, Anglo-Iranian Oil Co. Ltd. (*C. S. Newey*; *R. E. Adlington.*)

WATT, David Scott, geologist, Shell D'Arcy Petroleum Development Co. (Nigeria) Ltd. (————————)

WHARTON, Michael, Captain, R.A.S.C. (*P. F. Ellis*; *E. J. Horley.*)

WEBBER, Richard Hewlett, Major, R.A.S.C. (*P. F. Ellis*; *E. J. Horley.*)

WELLS, Dennis Ernest, draughtsman, Bahrein Petroleum Co. Ltd. (*K. S. Lennie*; *R. K. Smith.*)

WILLIAMSON, Norman, accountant, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

WORKER, John Roland, assistant quantity surveyor, Kuwait Oil Co. Ltd. (*G. A. Hogg*; *E. Boaden.*)

Transfers

BEGG, Arthur James, exploitation engineer, Anglo-Saxon Petroleum Co. Ltd. (*F. Morton*; *F. H. Garner.*) (*Student to Associate Fellow.*)

STEPHENSON, Ian Campbell, refinery operator, National Oil Pty. (*L. M. Lenny*; *I. R. Pryor.*) (*Student to Associate Fellow.*)

REID, Robert Curle McKellar, engineer agent, Freedom Valvoline Oil Co. (*J. M. Marshall*; *E. J. Horley.*) (*Associate Member to Member.*)

PHILLIPS, Clifford Kenneth, plant control chemist, Bahrein Oil Co. Ltd. (*W. T. Barrett*; *N. B. Watson.*) (*Student to Associate Fellow.*)

NEW MEMBERS

The following elections have been made by the Council in accordance with the By-laws.

Elections are subject to confirmation in accordance with the By-laws.

As Fellows

REYNOLDS, E. A. STEPHENSON, M. THALER, L. A.

As Members

FITZGERALD, J. C. GERSHON, J. C. HAYSE-GREGSON, P. B.

Transferred from Associate Member to Member

JOHNSON, S.

As Associate Fellows

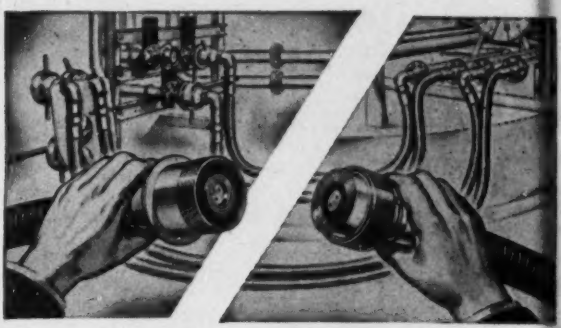
APPLETON, A. A.
BLACK, J.
BOYD, W. E.
FILMER, W. J.
GREGARTH, J. R.
HAMILTON-SMITH, P. A.
HOBSON, E. G. F.
MEHTA, M. M.
MOLYNEUX, J. H. B.
SHIPTON, J.
SMITH, G. W.
TAHIRALI, A. D.
WINNING, H.

As Associate Members

ALLINGTON, A. H.
ATKINSON, H. F.
CHINERY, H. R.
CLARK, E. S. E.
CRUSOE, C. G. H.
GODFREY, J. H.
MARLER, D. J.
MARSH, J. S.
MONTGOMERY, R. C.
ROWLEY, A. L.
VARTY, K. H.
WHITWORTH, R. A.

6C1

BREAK... without spilling...



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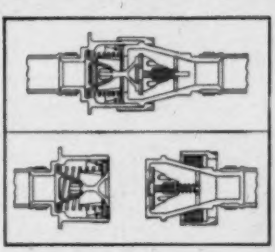

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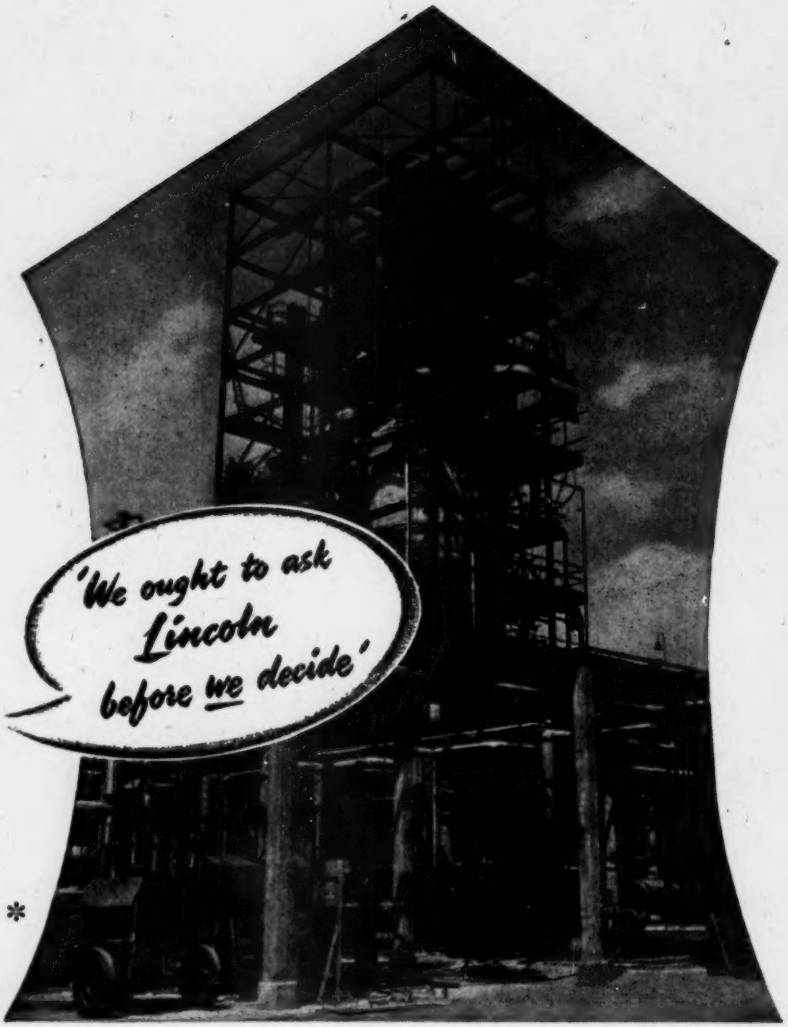

A Shell photograph

* *A Lincoln 300 Diesel—one of the Lincoln machines which with Lincoln electrodes have been used in the construction of this Feed Preparation Plant in the Shell Refinery at Shell Haven*

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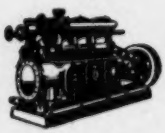

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Pulsometer–Pacific

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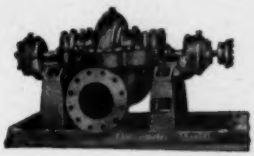
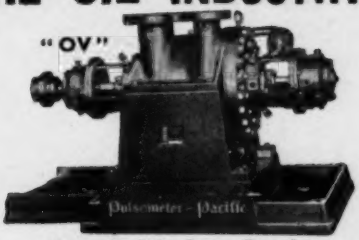


"KH"

Horizontally Split Casing Single-Stage Hot Oil Pumps.



Vertically Split Casing Two-Stage And Three-Stage Hot Oil Pumps.

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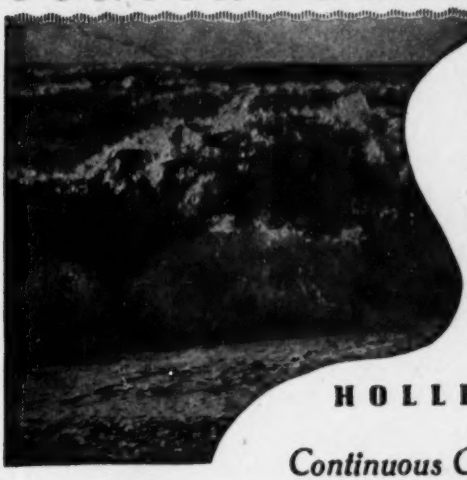

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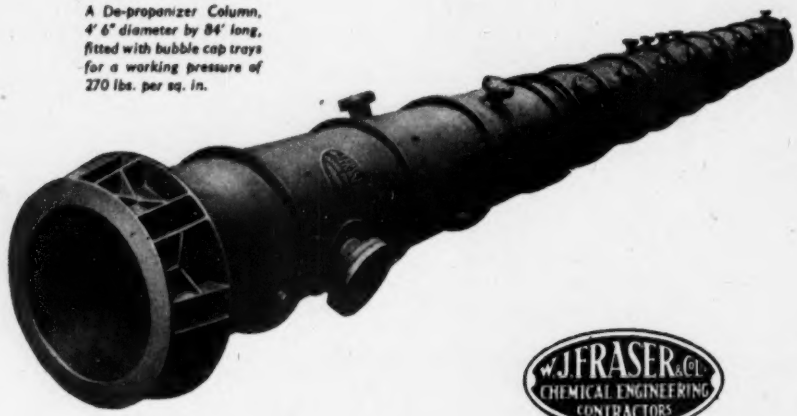

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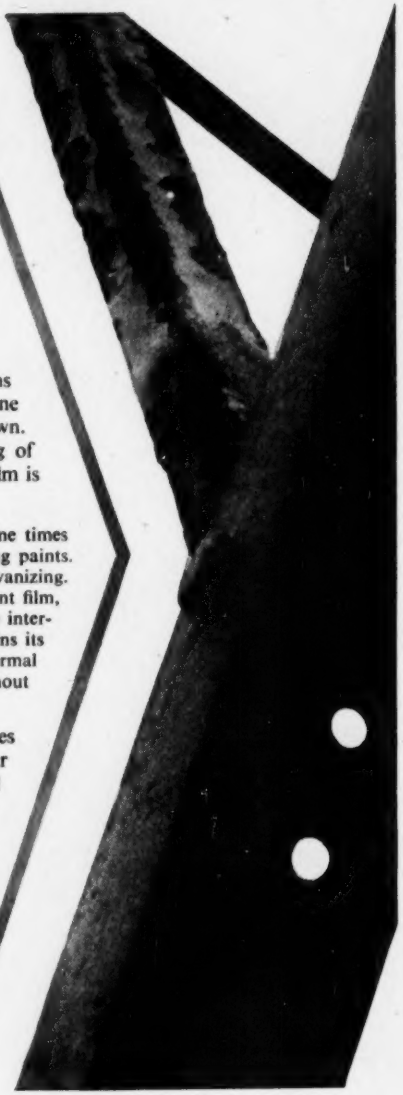

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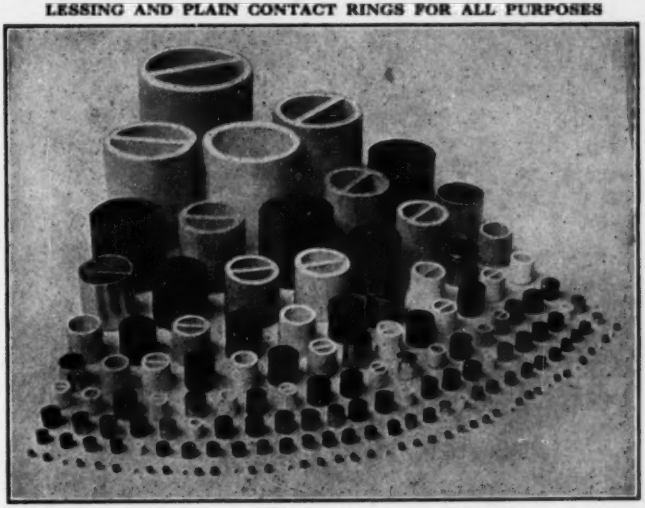

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The photograph shows view of furnaces on Pyrolysis Unit, Shell Chemical Plant, Stanlow, Cheshire, England.

A Shell Photograph

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for staggered disposition mounting
6 = 14 long

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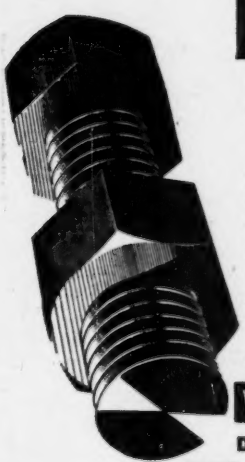

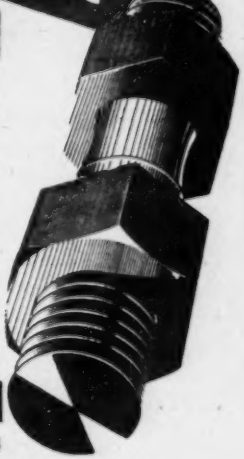

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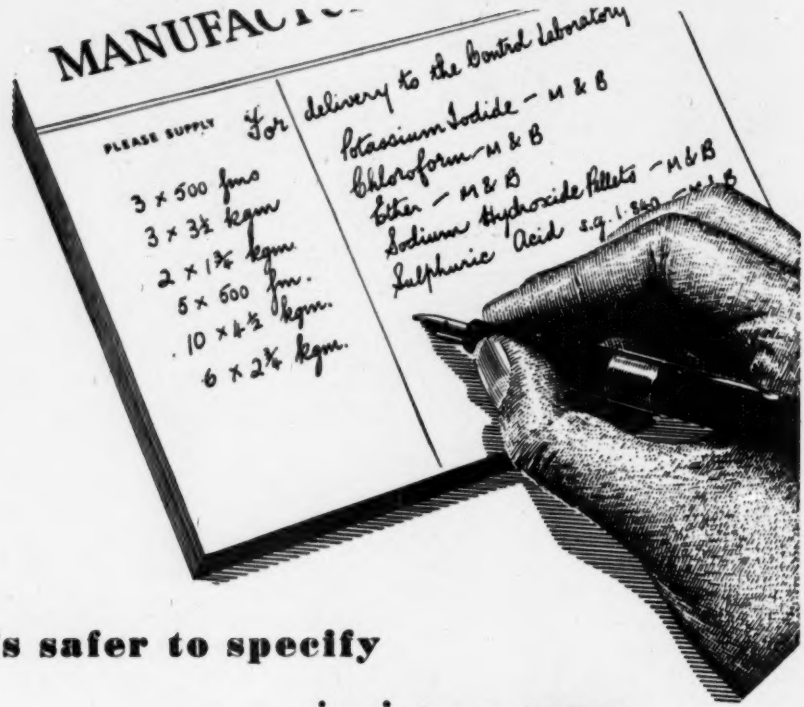
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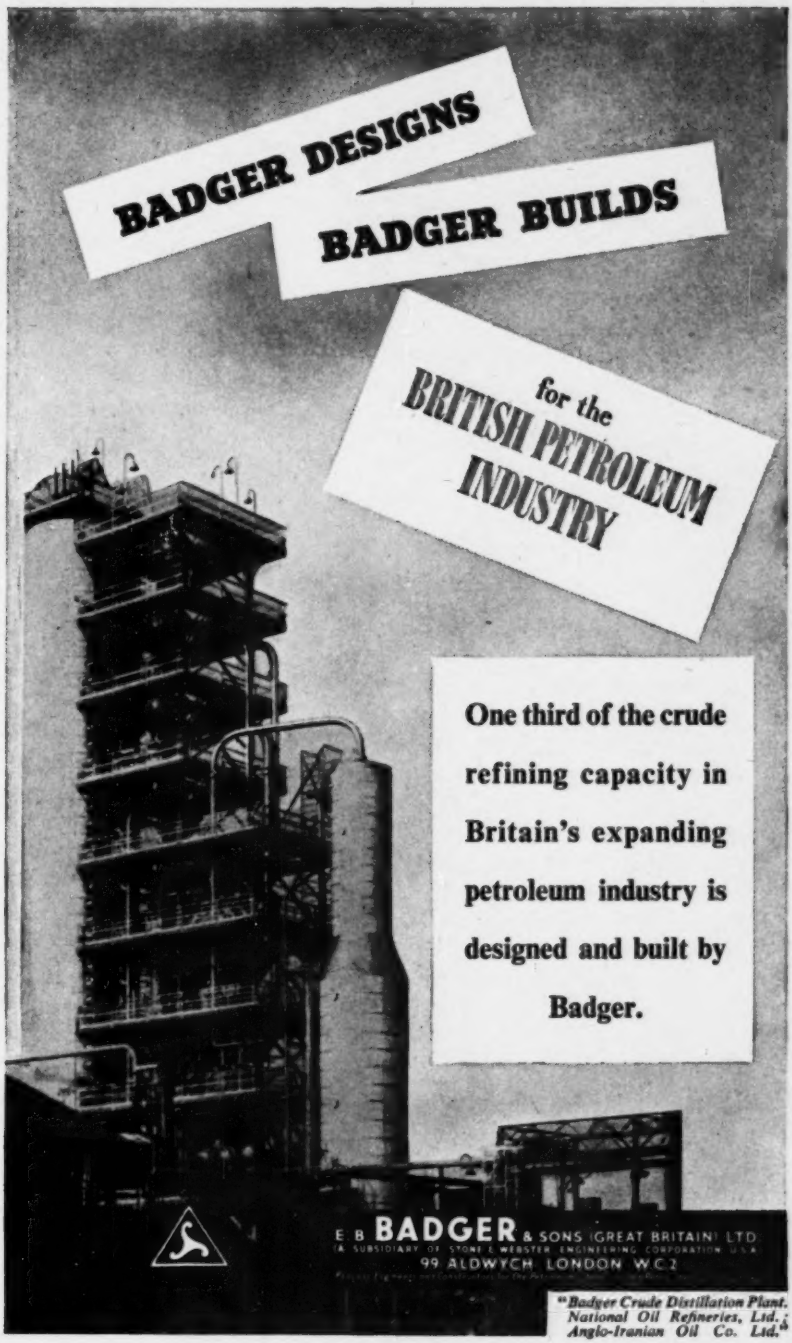
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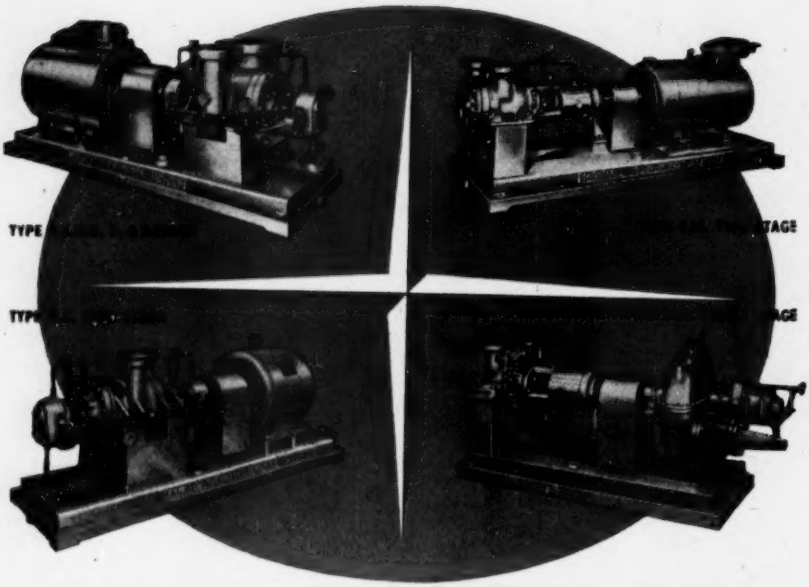

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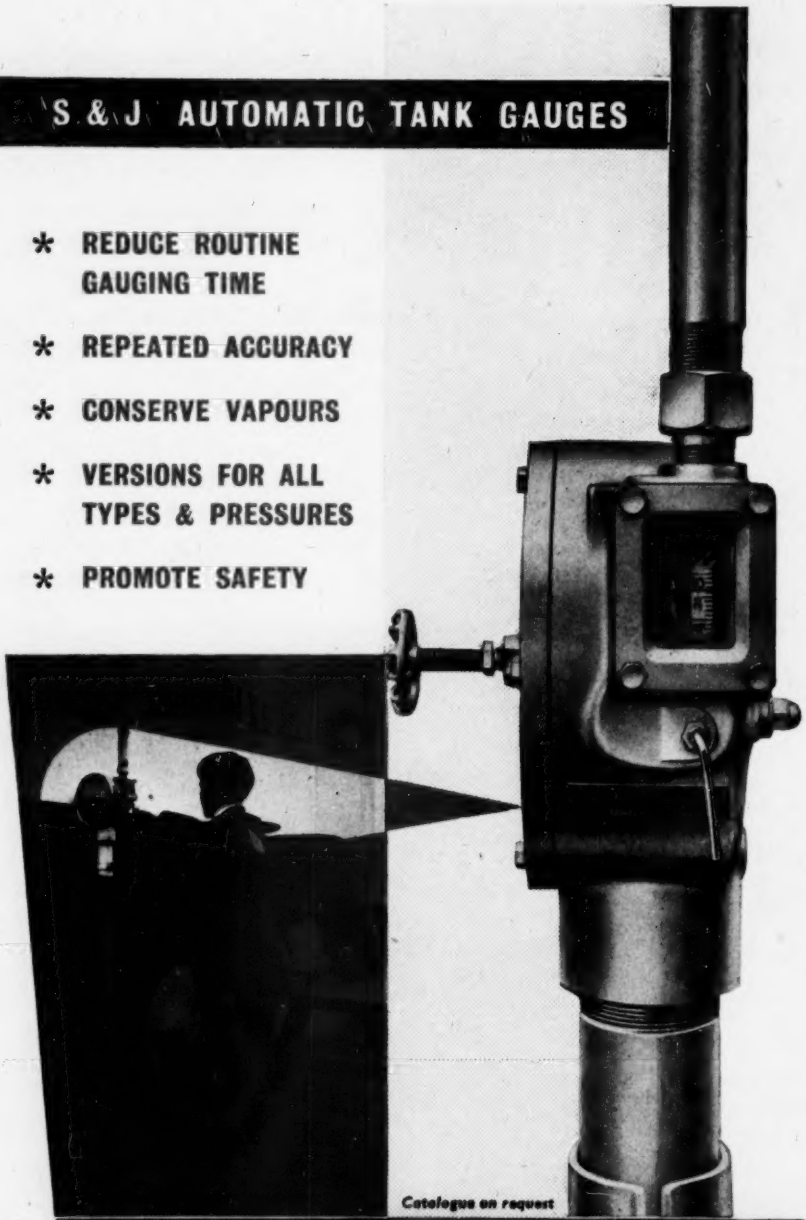

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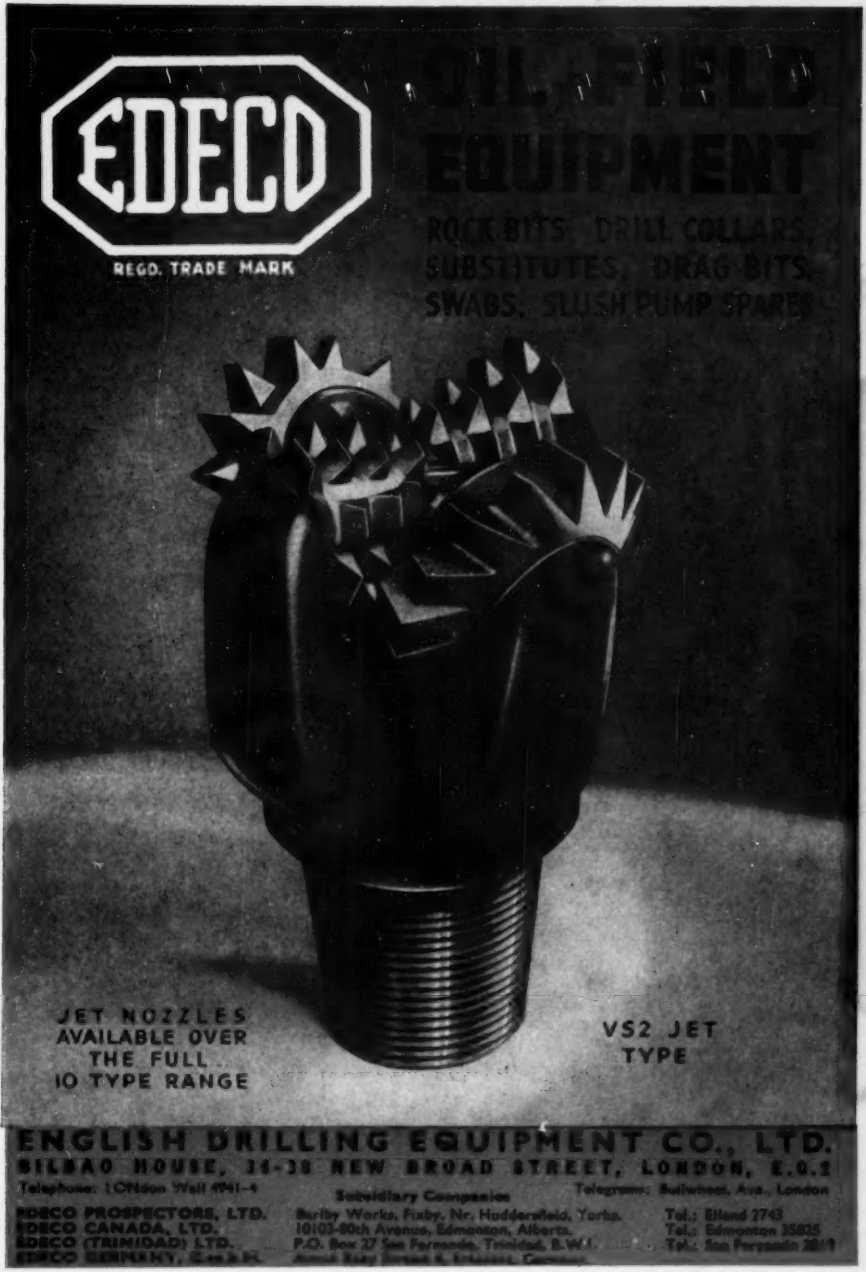
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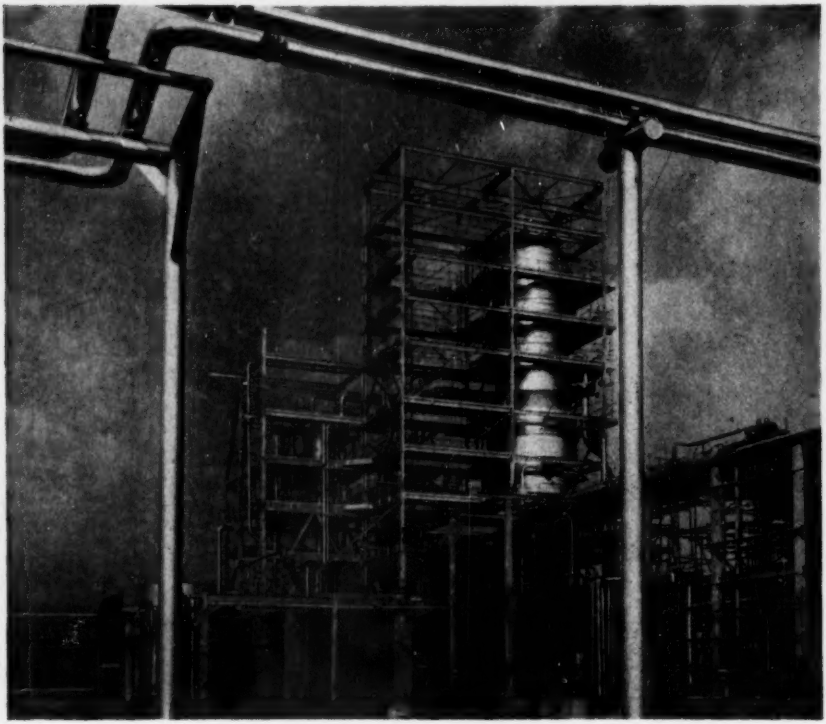

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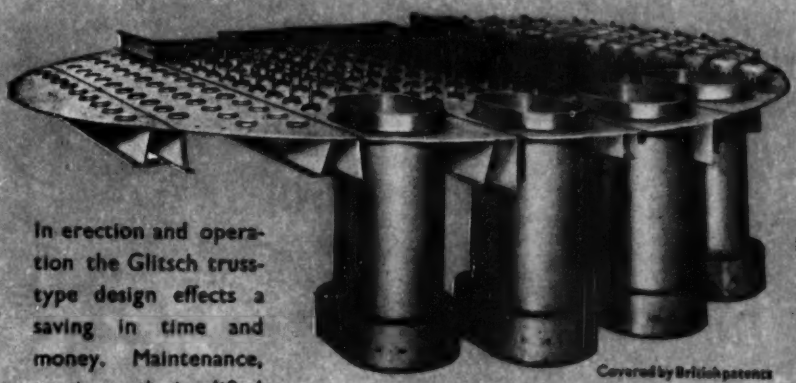

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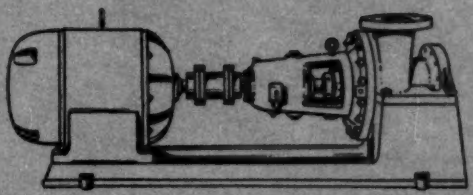

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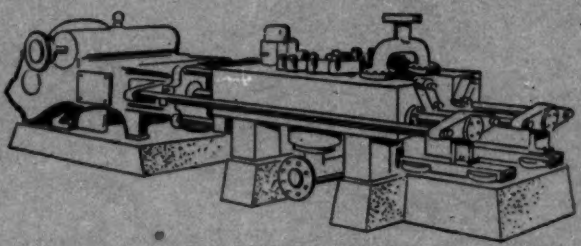

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